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TELESCOPE MAKING 45

The magazine *for, by*, **and** *about* **telescope makers!** **Summer 1991**

Telescope Making #45

The magazine *for*, *by*, and *about* telescope makers!

Editor: Richard Berry
Associate Editor: Peter Ceravolo

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In this issue...

2 **Editorial**

3 **Letters**

6 **A Motorized Cassegrain Secondary**
by Andrew J. Tomer and Mark Trueblood

10 **Doing it Right**
by Ed Stewart

16 **Western Hospitality Promotes Best Texas Star Pary Yet**
by Robert Reeves

22 **RTMC '91**
by Peter Ceravolo

30 **How to Make a Coma Corrector with O the-shelf Optics**
by David Shafer

34 **A Simple Procedure for Producing a Yolo Telescope**
by James Mulherin

38 **Ross Null Software**
by Doug George

44 **Blue Pages Classified Advertising**

Cover: Ed Stewart with his precision 12.5-inch f/4.8 wood-tube Newtonian. Stewart explains how to use standard woodworking tools, clever jigs, and computer graphics to make unusually precise and lightweight wooden telescopes.

Editorial

Once again, *Telescope Making* has done the impossible! Beginning with *TM#44*, we're being distributed on newsstands by Ubiquity Distributors. That doesn't mean you'll find *TM* on the news rack in every convenience store from coast to coast, but it does mean that an increasing number of people will discover the unique brand of fun that telescope builders enjoy.

Newsstand distribution offers *TM* some great benefits. Beginning with the next issue, *Telescope Making* will have a real cover instead of the present self-cover. That means that as your collection of magazines grows, they'll last longer and get less beat up. (Nonetheless, any magazine that people read while pushing glass will collect its share of cerox stains, pitch, and rouge!)

Another effect, perhaps less beneficial to you but of value to the magazine, is that the date on the cover (Summer 1991 for this issue) will be an off-sale date. The magazine must be dated several months ahead so that retailers keep the magazine up for sale until the off-sale date is reached.

To accomplish this, *TM#46* will be dated Winter 1991/92. Don't wait for the Fall issue—it'll never appear—and you'll still receive your full subscription.

Clear skies....

Richard Berry

Letters

Inspiration and Information!
Richard/ My, my! Mr. Numlist's polite letter requesting "occasional articles..." about "elementary" aspects of telescope making sure brought the wrath of the semi-pro optics jocks down hard, didn't it? Too bad. I don't think that's too outrageous a request.

I would ask that you and the crew remember that an enormous amount of the information you deal in is esoteric and — although inspiring to the freshman — absolutely useless. I take great comfort in articles like Dave Kriege's low-tech piece in *TM#44* as well as the amazing brass Refractor story by Larry Myers. Yikes! Inspiration and useable information all in one issue. That's what it's all about, right?

No one is asking for a TM devoted exclusively to making a scope from a shaving mirror. Ten years from now when I can actually understand it thoroughly, I'll re-read Mr. Douglas's piece on his hot apo doublet and enjoy it even more. Meanwhile I'll keep *TM* coming.

I'm glad your publication inspires me to learn about stuff that seems a mystery at first glance. Without the holy-cow-what's-this? factor it wouldn't be very exciting.

Fair winds.

Mark Roeyer
Roeyer Boats
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Lawrence, KS 66044

How to Find the Sky?
Richard/ I want to add my voice to those expressing a desire not to see TM become a vehicle to teach tyros which end of the telescope to look into. We have enough of that in both ASTRONOMY and *S&T*, which seem to be devoting more and more articles to telling the beginner how to find the sky. There also seems to be an endless stream of books coming off the presses for the same purpose. I think the public library needs to be rediscovered!

John J. Brooks
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Santa Ynez, CA 93460

Demise Assured without Novices
Richard/ On the matter of the beginners' articles in *TM*, I predict the demise of the magazine unless a small part of the content is attractive to newcomers. Without new subscribers to fill the ranks as old timers leave the scene, the subscriber list will go one way — down. How long would Kalmbach support a money-losing publication!

To illustrate my point, I have a few beginning barrel-walkers in my basement on Saturdays. Most of these guys subscribe to *TM*, but one person said that he decided not to subscribe after scanning his sample copy, because "the articles were too advanced." I had to agree and wonder at the same time how many others are turned away by the advanced articles.

It seems to me, the advanced amateurs had better support some *TM* space for beginners, or suffer the horrible fate of no *TM* at all.

Bill Herbert
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Columbus, OH 43212

— I want to thank TM*'s readers for the letters, faxes, and frantic phone calls on the "novice versus pro" question. Your vehemence, and the fact that both sides of the debate express their views with essentially equal vehemence, assures me that* Telescope Making *strikes very close to the proper as it exists today.*

As Mark Roeyer points out, stories like Larry Myers' brass refractor are intended less as how-to articles than for their inspirational value. Contrast it to Eddie Stewart's story, in this issue, which offers a lot of special constructional information, but information that's useful to you only if you're into wood construction techniques. For that matter, is Dave Kreige's story really low-tech, or it is nothing less than an insanely valuable story for every Dobsonian builder?

My goal with Telescope Making *has been to maintain a balance between inspirational and technical, mechanical and optical, woodworking and metalworking, novice and old-timer, cut-and-try and plan-and-execute, and meeting reports versus technical features. Peter Ceravolo,* TM*'s associate editor and optical wizard, is an excellent complement to my current interests in low-tech telescopes, CCDs, and image processing. Our interests are different and that's good for everyone.*

So here is our pledge: this magazine will continue to offer something for every reader. You may not find exactly what you want in every issue, but over the course of a year you'll find enough to keep you happy.

But as a reader of this magazine you must remember something else: Telescope Making has created and now serves a community of readers. We draw our stories from the readership, and those stories written on a voluntary basis. If you have expertise we need your help. If you have tips we need your help. Only if you share what you know with the rest of the community — both novice and old-timer — can the community prosper. —Richard

How to Strip Old Aluminum
Dear Richard/ Because I do a considerable amount of mirror refiguring it is important that I have an easy way to strip the old coating. Until recently I had been using sodium hydroxide, which takes hours sometimes and needs to be warm to work. This can also be quite dangerous to your health if done indoors. The last mirror I stripped was a 13.1-incher and took almost 24 hours.

After that one, I talked to our coating engineer at work and he recommended Archer PCB Etchant Solution from Radio Shack. A bottle of this solution costs about $3.00. PCB etchant is used for making PC boards. It does not harm the glass, does not need to be heated, and can be done without the windows open.

The best way is to submerge the mirror in the solution, but because I usually work on large mirrors, I simply pour the solution on the mirror and spread it around with a paintbrush. The solution must sit on the surface for 5 to 10 minutes in order to work, so it should be moved around every 5 minutes or so. Stripping a 13-inch mirror takes about 30 minutes.

Richard J. Wessling
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Domestic Amateur Paradise
Richard/ I read with great interest "The Amateur Paradise of Dany Cardœn" published in in *TM#43*. It sounds like a wonderful facility and I hope to be able to visit one day!

We operate a similar facility in New Mexico called the Star Hill Inn. We have been open since June 1988 and have hosted over 800 amateurs from 42 states and 7 countries. Our repeat business is currently over 20 percent. Please come for a visit in the future!

Phil Mahon
Star Hill Inn
Sapello, NM 87745

— From the brochure enclosed with the letter, the Star Hill Inn sounds wonderful. Here are some quotes: "Our goal at Star Hill Inn is to create the ideal 'getaway' for amateur astronomers, a place for vacation and retreat with colleagues and friends with similar interests..."

"...views of these natural wonders [of the sky] are enhanced by using the Observatories International computer-assisted 24-inch Schmidt-Cassegrain or one of the other telescopes available, truly exceptional observing and photographic experiences are possible..."

"...each cottage has modern heat, a fully equipped kitchen, private porch and its own cozy fireplace. We're an ideal size for small groups, as well as individuals and families. The rates also include use of a 'scope pad for whatever equipment you'd like to bring as well as a warming room and library adjacent to the observing area."

Bubble Cells are Visual
Richard/ In the last year I've noticed several stories relating to "floating" thin mirrors in their mirror cells. The latest note on this recommended using bubble pack as a floatation device. I've had five years of experience with a very thin 10.5-inch mirror (21:1 aspect). I "floated" this mirror on three pads of foam rubber. The pads were kidney-bean shaped, each supporting a 100-degree sector of the mirror, and only a quarter-inch thick. This cell served quite well for VISUAL use; several thousand variable

Letters

star measures have been made with it.

Photographically it's a disaster. The soft quality that is so desirable for the thin mirror causes changes in the distance between the focal plane and mirror during long exposures as the telescope changes position while tracking. Although these changes are small, at f/3.95 even a thousandth of an inch is ruinous.

While the soft "floating" cells are fine for visual use, it seems that a hard, multi-point floatation is best for the long exposure astrophotographer.

Richard E. Hill
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Sagging Mirrors: Wavefront Counts!

Richard/ This letter is in response to Herbert Highstone's letter in *TM#44* on sagging mirrors. The problem he poses is really rather intriguing. My first assumption was that his analysis of the sag of an optical mirror was faulty. On doing my own analysis, using both a 20-inch lightweight mirror and a full-thickness mirror, I found that, if anything, his estimate of 5 waves over 20 years is probably on the conservative side.

Why then don't we see mirrors degrading over their lifetime? The answer is that a 5-wave sag does not induce a 5-wave error in the wavefront. We must ask not how much the mirror will sag, but what effect such a sag might have on the total wave-front error of the mirror.

To understand this, consider what shape the parabolic mirror takes on after sagging. We can consider such a mirror to be the sum of three components: 1) a spherical circle of revolution, to which is added 2) a correction which brings the mirror to a paraboloid, plus 3) another correction due to any sag. In this analysis, I have assumed that the sag itself is a circle of revolution rather than a buckling due to improper support.

Consider the case where the circle of revolution due to sagging is itself a paraboloid. The net result of the sum of these three components, really the sum of two paraboloids, is another paraboloid with a different focal length. With a 5-wave sag, the focal-length change will be less than $^1/_{25}$ inch, too small to be readily measured. The mirror will be as good as before as far as wave-front error is concerned.

The second case to consider is a spheroidal sag. If we add this sag to the original spheroid we get a new spheroid with a slightly shorter focal length. To this new spheroid has been added the correction which was put onto the original spheroid. The sagging mirror will be improperly corrected, but the total wave-front error calculation shows this error to be extremely small, less than $^1/_{300}$-wave for a 20-inch f/5 with a 5-wave sag.

Mechanical engineering tests tell us that thin beams suspended at their ends sag hyperbolically and I suspect a plate will as well, although I couldn't find a text that would confirm this. I did wave-front calculations with various degrees of hyperbolic sag and in all cases found that a 5-wave sag would produce extremely small total wave-front errors as well as very small changes to the focal length.

The conclusions I came to are that if mirrors actaully do sag over time, as long as it remains a circle of revolution, the sag will have a negligible effect on the performance of a parabolic mirror.

Don Ware
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Hollis, NH 03049

Mirrors Really Do Sag!

Richard/ I would like to comment on the question of sagging glass raised by Herbert Highstone in *TM#44*. Most glass, including Pyrex glass popular for telescope mirrors, is actually a very "thick" liquid! The rate at which glass sags depends not only on the stress, but also on the viscosity of the glass, which is a measure of how strongly the glass resists sagging, so that:

Strain rate = Stress/Viscosity

As a point of reference, water has a viscosity of 0.01 poise, while glasses typically have a viscosity of over 10E16 poise! So, while glass is a liquid, it sags quite slowly, like very, very cold molasses. Therefore, to address the issue of sagging glass, we must consider not only the stress on the glass, but also its viscosity.

Let's consider the stress first. The stress analysis of a uniformly loaded circular plate supported along its periphery is given in "Theory of Elasticity" by S. Timoshenko and J. Goodier. The maximum stress occurs at the bottom surface of the center of the plate:

Stress = (Span^2 x Load)/Thickness^2

However, the uniform load depends on the thickness of the glass, since the load is due to the weight per unit area (Density x Thickness) of the glass. Therefore, the final stress is given by:

Stress = (Span^2 x Density)/Thickness

Most cafe tables use $^1/_4$-inch-thick plate glass, while a 20-inch mirror will be roughly 2 inches thick. The unsupported span in our cafe table is 20 inches, and the unsupported span in a well-supported 20-inch mirror is likely to be about 4 inches. Because the density of glass is nearly the same as that of Pyrex, the ratio of the stress in the mirror to the stress in the table is given by:

[Mirror Stress]/[Table Stress]

= [(4"x4")(2")]/[(20"x20")/($^1/_4$")] = $^1/_{200}$

Thus we see that the mirror has a stress about 200 times lower than the cafe table.

The second point to consider is the viscosity of the two materials. The viscosity of glass depends strongly on both temperature and composition. A difference in 100° Celsius can change the viscosity of a given glass by a factor of 1000. Pyrex is a borosilicate glass developed for its low coefficient of thermal expansion (good for telescope mirrors!) and its improved high-temperature properties. Soda-lime silica glass popular for many windows and (cheap) cafe tables is easy to form into plate glass because of the low temperature at which it can be softened and "floated" into plates.

The softening point of Pyrex is 125° C higher than typical plate glass, which translates to a viscosity roughly 200 times higher. Therefore, it is reasonable to expect that Pyrex glass will sag roughly 200 times slower than a typical plate glass.

If we now combine these two effects, we see that the 20-inch Pyrex mirror will sag about 40,000 times more slowly than the cafe table. Using the analogy given by Highstone, while the cafe table will sag 25,000 wavelengths in 20 years, our mirror will sag $^5/_8$ wavelengths, or $^1/_{32}$ wavelength per year (which translates to a $^1/_4$ wavefront error every 4 years!).

Bear in mind that this is a rough estimate, and assumes that both the mirror and the table are always the same temperature (the cafe table has likely seen its share of time on a warm sidewalk or patio, while the mirror is rarely warmed by the sun's rays) and that the only loading is due to the weight of the glass (the cafe table almost certainly supports other loads, including a perpetual flower vase and an occasional Reuben sandwich).

Each of these effects would cause the cafe table to sag much more quickly, so the rate at which our mirror sags is proportionately slower. Nonetheless, the concern raised by Highstone is quite valid, and we should perhaps remember to support our mirrors well and to protect our mirrors from extreme or unnecessary heat whenever possible.

Dan Miracle
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Glass Sagging: No Way!

Richard/ Herbert Highstone's letter on the sagging of glass raises an interesting point. However, our glass consultant (I work at the Santa Barbara Research Center) says that glass is not a supercooled liquid and does not flow under stress with time. He says that glass is a polycrystalline solid which will not creep measurable amounts during the sorts of times which concern us in spite of anecdotal data to the contrary.

Distortion probably occurs in glass which has not been properly annealed to relieve internal stresses. Removal of material during mirror fabrication in improperly annealed glass will change the internal stress distribution and result in a shape change which continues as

more glass is removed to correct that change, and so forth.

This old debate about the creep of glass with time will go on ad infinitum. Those who think it does must provide hard data to prove their case.

John J. Brooks
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Make A Mirror? You Must Be Kidding!

Richard/ Over and over again I've heard the complaint, "I cannot purchase a set of commercial optics that produces excellent optical images for a cost within reality." WHY? Because the commercial optics suppliers cannot spend the time it takes to make a 20" mirror with a true $^1/_{10}$th wavefront for $1,200 and still make money. Have any of you amateurs made a 20" mirror and experienced the time involved in refining the surface to just $^1/_4$ wave accuracy? If you have, you know what I am talking about. The question arises: just what kind of optical quality am I looking for? What is a perfect star image and how will I know if it is perfect? Recognizing perfect star images comes from looking through many telescopes, commercial, handmade or otherwise, for many years. Once you've seen the ideal "perfect" star image you will never forget the sight you have witnessed. To achieve this kind of optical accuracy though is rare because time is money and unfortunately this premise has dominated the optical industry to the point where "time is too short." Well, what is the answer to the amateur's optical dilemma? It's very simple, do it yourself! Only you know what you want. Does this sound like a lot of work? Well it is; and I would be lying if I stated otherwise, but the fact is we are in the age of LAZINESS and just can't seem to find the time to make quality optics ourselves. We are depending on the manufacturers, but they can't afford to spend the time on them either. I realize not everyone is an optician and I also realize a lot of amateurs do not have idle time. However, if this is the case how could I work two jobs, support a wife and three kids and go to college part time and still have time to complete a 20-inch mirror very satisfying to my taste? STUBBORNNESS is the answer! Why would I have an 8-inch mirror aluminized four times? The answer is I thought I had it "perfect" each time. Only when I looked through superior scopes including maks and refractors did I realize the clear astronomical world I was missing.

Make it myself you ask? Where do I get all the information and who do I talk to if I run into problems? Well, many a telescope mirror has been fabricated over the telephone. Attending a few telescope conventions and talking to experienced scope makers doesn't hurt either. Publications released on mirror making or lens making have never before been so plentiful. Try finding the information we have now back in 1925! At the end of this article I have included a list of excellent sources written by people who can explain optics in layman's terms.

Is it any wonder we're mad? Mad at the commercial optical fabricators or frustrated with ourselves for not realizing we can make the high-quality optical surfaces at a cost we can afford. As long as we accept the commercial optics available for lower prices or even higher prices and are not willing to make it ourselves, then we are the fools, not the commercial suppliers!

Amateur Telescope Making, Books 1, 2, and 3, William Bell Company, P.O. Box 35025, Richmond, VA 23235, (804)320-7016

Advanced Telescope Making Techniques (Optics), by Allan Macintosh, William Bell Company

How to Make a Telescope, by Jean Texereau, William Bell Company

All about Telescopes, by Sam Brown, Edmund Scientific Company, 101 First Gloucester Pike, Barrington, NJ 08007

Homebuilt Reflector Telescopes, by Sam Brown, Edmund Scientific Company

Ray Greenman
10978 Rocky Road
Bent Mountain, VA 24059

Big Doin's Down Under

Richard/ Greetings from one of your far-off Southern Hemisphere subscribers to *Telescope Making*. I certainly look forward to each copy every three months. I am now "retired" but I was engaged in optical engineering, working at the "Physics and Engineering Laboratory" — Department of Scientific and Industrial Research. This is a Government Department, and is perhaps equivalent to the U.S. Bureau of Standards. I spent a very interesting time, with Norman Rumsey (another *TM* subscriber), designing and making optical instruments, from microlithographic lenses for silicon wafer research, to the Zerodur optics of a 40-inch f/3.5-13.5 Cassegrain telescope at the Mt. John University Observatory. Other projects included optics for an echelle spectrograph, plus the designing and making of CCD and Reticon retrofitted cameras for Boller and Chivens Cassegrain spectrographs.... So much about my background. Even though retired, I am still associated with the Mt. John Observatory in a lot of their instrumental requirements.

I wrote to Dick Suiter and obtained his mirror testing routines. They have proved most valuable, and certainly allow an un-ambiguous figure of merit to be placed on mirror quality. Personally I prefer to test my paraboloid primaries and hyperboloid secondaries in autocollimation against an impeccable flat. The problem for most people is the flat...more especially in obtaining a really smooth ripple-free surface. All the null tests using auxiliary optics that I have traced to date tend to exhibit some very slight zonal residues. Perhaps that is nit-picking, but the tolerances on spacings using the flat are of lesser importance. Figuring Cass secondaries against their paraboloid primaries in double pass allows you to set a precise tail length with comparative ease.

We are fortunate to have Peter Ceravolo as associate editor. His notes on the Ross Null test and mirror figuring were superb. These, I hope, will be taken on board by the amateur fraternity, to produce high-grade optics. I used a two-mirror all-reflecting null corrector, made from Zerdur blanks, for the big 40-inch mirror, but the spacing sensitivity calculations showed the importance of getting the distances CORRECT. We updated the parameters to compensate for the slight changes in the paraxial radius, during the aspheric figuring procedures.

My other interest is astrophotography using Schmidt and Lurie variants. These catadioptrics leave all refracting lens systems way behind. I was amazed to find that a small 6-inch f/3 classical Schmidt in my backyard reached, in 15 minutes' exposure, to just on 18th magnitude on an NGC 121 sequence by Tifft! That result was due to hypered 4415 Tech Pan of course! The faintest images measured around 8 to 10 microns depending upon seeing. It is ideal for medium-speed Schmidts. f/3 seems to me to be the optimal trade-off, considering all the optical and mechanical factors involved. I do not advocate f/1 to 1.5 Schmidts...they are very difficult to maintain the focus constant, and the sky fog with hypered emulsions is very severe.

I have just designed a "planetary" telescope of 8 inches aperture, using an f/6 Hyperboloid primary with a window-mounted 2x apo-Barlow to give f/12. It looks excellent on paper, but I would like to make it up first. I tend to agree with the late Bob Cox, that a prototype should be first made to overcome any bugs. So hopefully, that project is for the near future! It is rather similar in outline to the Rutten Newtonian presented in *TM#35*. I have tried to keep the obscuration ratio down to about 12%.

It is good to read that the old Bi-Optical firm, now Newport Glass Works, is providing an access to glass supplies for advanced ATMs. I have just received the latest Schott-Mainz optical glass price list, and their minimum order is now DM500! The good old days of HC and DF refractor blanks from Chance Bros or BSC-2 and DF-2 from Bausch and Lomb are long since gone! I have some interesting letters from Albert "Unk" Ingalls, from way back in the late 40s, when I was a very raw recruit, making my first 8-inch f/8 Newt. Likewise I corresponded with Horace Dall over a long period and enjoyed immensely having him stay with us when he visited New Zealand back in 1965!

Finally, very many thanks for your efforts on behalf of the telescope-making fraternity.

Garry R. Nankivell
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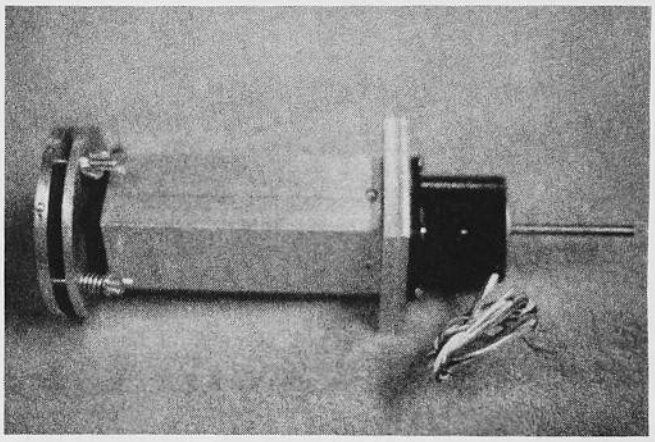
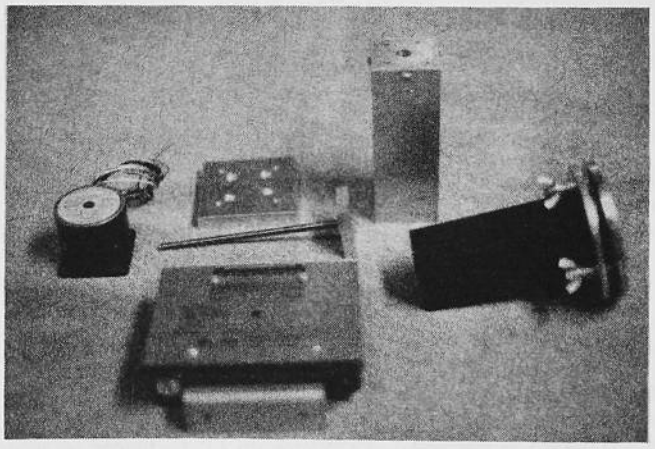
Australia

A Motorized Cassegrain Secondary

Simple ideas sometimes make life a whole lot easier. In this story we offer a few simple ideas here that can make your telescope building faster and your observing more fun. These are 1) a focussing secondary assembly that uses a sliding plastic plug and 2) a gimbal assembly for adjusting both the primary and secondary mirrors from the same place near the eyepiece at the Cassegrain focus. The ideas presented here are Tomer's, and Tomer also built the primary mirror gimbal assembly. Trueblood built the secondary mirror focuser and gimbal assembly.





Focusing a Cassegrain telescope requires a mechanism that is free of slop and wiggle. A small motor moves a tight-fitting Delrin plug that carries the secondary. The completed unit is mounted inside the telecope tube.

Focusing Assembly

Anyone who has used a telescope for critical imaging realizes the importance of accurate focus. Modern electronic image sensors and photographic plates and film demand perfect focus. If you are measuring plates to determine the position of a star, a planet, or an asteroid, star images cannot be larger than a few film grains.

Adjusting the focus should be smooth and fast. To perform well, focus mechanisms must be accurate, repeatable, and precise (typically 0.001 to 0.0001 inch). In addition, they must be mechanically stable. Those who control their telescopes by computer also need a simple and inexpensive computer interface to the focus mechanism. These are tough requirements by any standard.

An added complication for Trueblood, who directs the Winer Mobile Observatory, is that the focuser he uses in the 12.5-inch aperture telescope he is building must be able to withstand vibration. The telescope is mounted on a trailer and is sometimes towed over rough roads to remote observing sites. Tomer designed the focuser with this application in mind as well as cost and simplicity of fabrication.

The traditional approach to focusing a Newtonian or similar two-mirror design is to fix the secondary mirror in the tube or truss with a rigid spider assembly, and then to add a couple of ways to adjust the position of the secondary to align the optics. Once adjusted, the position of the secondary mirror is not intentionally changed. Images are brought to a focus in these designs by moving the eyepiece.

In contrast, Cassegrain systems are often focused by moving the secondary mirror closer to or farther from the primary. This approach is used even for relatively small Cassegrains, as discussed in this article.

The advantages of this design are ease of construction (especially if you can get the use of a vertical mill)

and smoothness of operation. One disadvantage is that if you don't have a cheap source of plastic, the materials can be somewhat expensive.

The secondary mirror assembly described below is used in a 12.5-inch Dall-Kirkham Cassegrain telescope designed by Robert N. Bolster for photoelectric photometry. The narrow field of view and coma inherent in this design are of no consequence since the photometer is used to observe compact objects on axis, where optical performance is excellent. The f/3.5 primary and the secondary magnification factor of about 3.14 combine for an overall speed of f/11. This is to accommodate the high-speed photometer which was designed at Lowell Observatory for use with a C-14. The secondary mirror is 4 inches in diameter and one inch thick, and weighs approximately one pound with its cell.

Moving a Cassegrain secondary displaces the focus by the square of the secondary magnification factor. In this design, one inch of secondary mirror travel alters the focus by 9.88 inches. To control the focus to a precision of 0.001 inch, the secondary mirror position must be controlled to about 0.0001 inch.

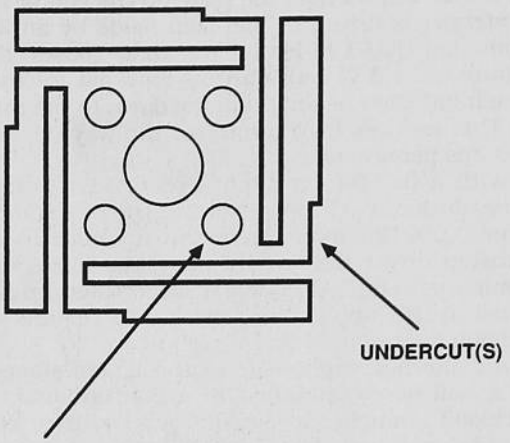
Another problem with Cassegrain optical designs is that they are sensitive to lateral shifts and tilts of one mirror with respect to each other. While only a short travel along the telescope axis is required, this travel must be straight, smooth, repeatable, and controllable to high precision.

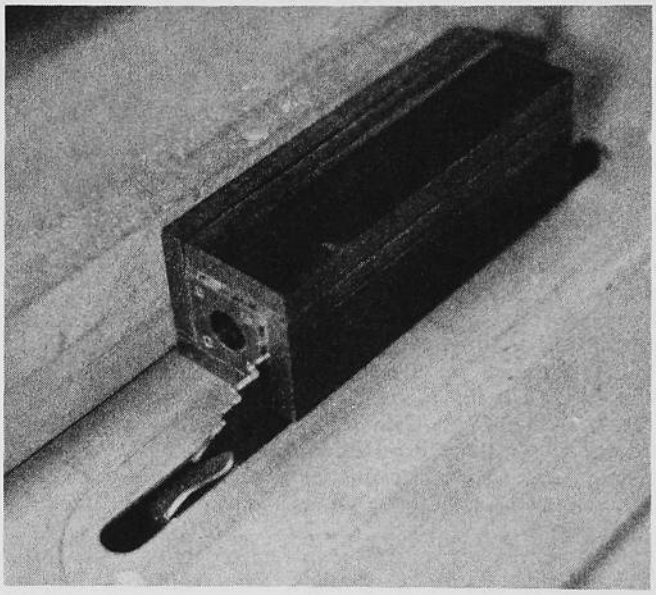
This can be a tall order. Group 128, a manufacturer of professional telescopes in the 1960s and 1970s, used a single large Thompson precision-ground stainless steel rod and an adjustable linear ball bushing to control the motion of its Cassegrain secondary. It took considerable effort to get the bushing adjusted correctly for smooth and straight travel.

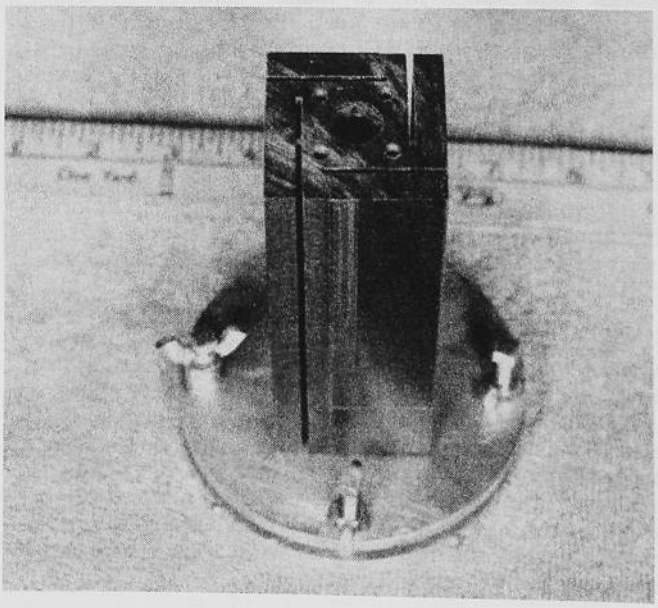
While he was a student at Wesleyan University in 1972, Tomer attempted to build a focuser with three 0.25-inch Thompson rods, linear ball bushings, and two aluminum cylinders, one of which housed a DC gearhead motor. Even after considerable effort spent in aligning a Bridgeport mill to drill accurate holes for the rods and bushings, Tomer gave up on the design when he encountered excessive binding of the bushings on the rods, resulting from small misalignments. He then turned to using a cylinder of Teflon guiding a single shaft in a slightly undersized hole. This is the design he currently uses in his 12.5-inch classical Cassegrain trailer-mounted telescope.

In response to Trueblood's design request, Tomer improved this basic arrangement by using Delrin rather than Teflon. Teflon is unstable and cold-flows to distorted shapes. He also designed the focuser so that the plastic part moves. This means that the moving plug must be some cross section other than circular so that it does not rotate when it is driven by a screw. Refer to the figure showing Trueblood's assembly disassembled.

In this design, a linear stepper motor (model 23A108A from Anaheim Automation, 910 E. Orangefair Lane, Anaheim, CA 92801, phone 714-992-6990) provides the back and forth driving force. The motor turns a 0.050-inch-pitch nut inside its housing to move the lead screw. Because the screw does not turn with respect to







The Delrin plastic plug is the key to the successful operation of the motorized focuser. Undercuts made in the Delrin block with a table saw act like springs to center and guide the focus slider.

the plastic plug, it is fastened to the plug with a plate. Four #4-40 screws hold the plate on the end of the plug. The stepper is driven in half-step mode by an Anaheim Automation BLB-1 bi-level driver that "gooses" the stepper (rated at 1.3 V) with 45 volts for a few microseconds on each half-step before dropping down to the rated voltage. This ensures high torque all the way up to 20,000 half-steps per second.

With a 0.050-inch pitch screw and 400 half-steps per revolution, each pulse sent to the driver moves the mirror 0.000125 inch. Anaheim Automation makes a microstep driver that would move the mirror one-fifth as much per step. Although the microstep driver is not needed in this application, those who require a higher precision focus would find it useful.

An alternate approach to the linear stepper is to use a ball screw attached to a conventional stepper. Trueblood bought a small ball screw with five "threads" per inch for $2 at a ham fest a few years ago. You can often find steppers at ham fests for less than $10 each. The disadvantages are that 1) you need to drill a hole through the length of the Delrin plug to accommodate the ball screw, 2) you need to find a way to attach the "nut" to the plug, and 3) the coarse thread requires microstepping to obtain a small linear travel per step. However, this approach avoids having the lead screw stick out the back of the linear stepper. Be sure to attach the screw to the stepper with a vibration damping coupler. Suitable couplers are available from Lovejoy and Berg.

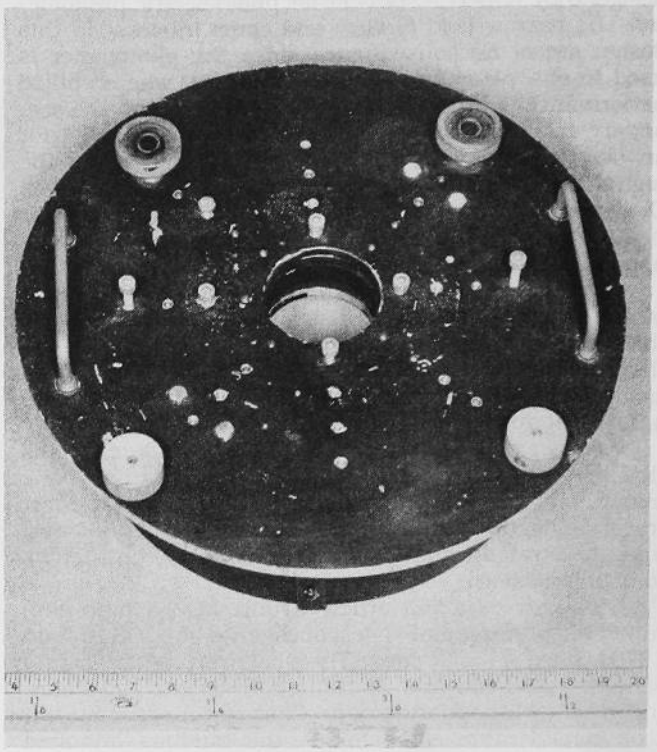
Four #10-24 screws hold the motor onto a motor mount plate made of 0.5-inch-thick aluminum. This plate is screwed to another 0.5-inch-thick aluminum plate sized to just fit inside the 2-inch square by 5-inch long extruded aluminum housing. Four $^1/_4$-20 threaded rods attach the secondary mirror cell to an aluminum disk screwed to the Delrin plug with four #6-32 flathead screws countersunk into the disk. Washers can be placed on the threaded rods to adjust the tilt of the secondary mirror cell with respect to the aluminum housing. Once these tilts are found, there should be no need to change them. The photo shows a prototype gimbal assembly floating on a ball bearing.

The secondary mirror is attached to its cell with RTV silicone adhesive sealant. This material helps absorb road shock in our trailer-mounted telescope. Safety clips and a chain keep the mirror from falling onto the primary if the RTV ever lets loose or some critical screws back out.

A trick that Tomer uses to attach a threaded rod to a plate is to drill and tap a hole in the plate and screw the rod in and then use a hammer and center punch to create several small dimples around the rod about $^1/_{16}$ inch from it. The metal displaced by the punch deforms the tapped hole slightly and effectively "welds" the rod to the plate. This works best in soft metals such as aluminum.

There are two key elements to making this design successful: consistency of the inside dimensions of the extruded aluminum, and the close tolerances on the dimensions of the contact surfaces of the Delrin plug. It turns out that 2x2-inch extruded aluminum is both relatively easy to find and has extremely consistent inside dimensions. To find a short piece of it, talk to makers of aluminum windows and doors listed in the yellow pages under Aluminum Products. Avoid wholesale aluminum distributors who want to sell only large quantities (for example, 21 feet).

The mirror cell uses orthogonal screws for easier and more efficient collimation. Note that four screws are used for moving the primary mirror cell. The side view shows the aluminum gimbal assembly behind the cell.

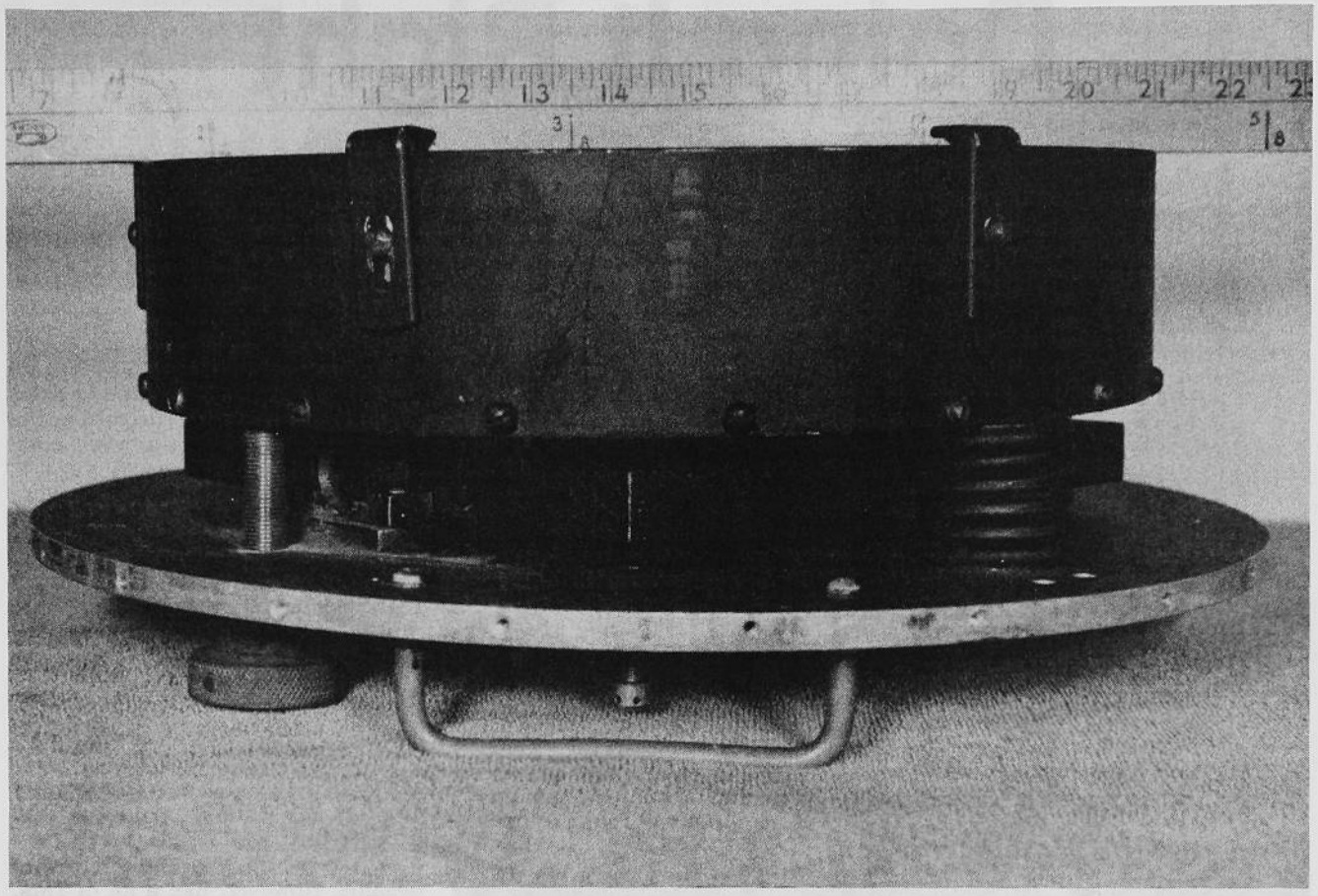


The Delrin plug is shown conceptually in an accompanying drawing and the completed assembly in a photograph. The design keeps the plug centered in the housing and moving straight. The slots allow the sides of the plug to bend slightly inward while using the restoring force of the plastic as a spring to hold the sides of the plug against the walls of the extruded aluminum housing. Trueblood used a milling machine to make the outer dimensions of the plug about 0.005 inches larger than the inside dimension of the aluminum housing. The 0.020-inch undercuts were then made with a single pass of the mill on each side.

The long slot cuts were made with a table saw using an 8-inch hollow ground blade. The fence was set to make the width of the compression "arm" about 0.25 inches. Cutting Delrin with a blade made for wood really isn't so bad. It does make a lot of small chips that seem to go everywhere, so be sure to wear goggles and keep your fingers away from the blade. Make each cut in stages, taking another quarter inch with each pass.

After machining, spread a generous amount of lithium grease on the plug. This will help you to get it into the housing and will reduce friction in use, especially winter use. You may have to adjust the outer dimensions of the contact area to get the right feel, or even make a second undercut from the other direction on each side, leaving a smaller contact surface on the center of each side.

Because the secondary mirror needs to move only about an inch, the completed assembly could be made a little shorter than shown in the photograph. A good rule of thumb is to have at least two-thirds of the plug still in the housing, keeping the linear travel straight and true when the plug is at its maximum



extension. That ratio depends on the weight of the secondary mirror.

Gimbal Primary and Secondary Mounts

Once the secondary focuser is built, it must be mounted in the tube in a way that can be adjusted to keep it aligned. This is especially important for a portable telescope. Cassegrains are particularly sensitive to misalignments, so a quick and convenient way to bring the optics back into alignment after a long road trip is a real necessity. If you use a portable telescope to observe occultation events that just won't wait for you to finish aligning your optics, this will be doubly appreciated.

Most TMs use three screws spaced 120 degrees apart to adjust mirrors. We don't understand why. All three screws interact with each other, so turning one screw ruins the adjustment you just made on another one. It's really quite simple to make a double gimbal adjustment for both primary and secondary mirrors using two screws for each mirror. In Tomer's design, all four screws are located close to the eyepiece at the Cassegrain focus behind the primary mirror cell. The top two screws tilt the primary mirror cell, while the bottom screws adjust the secondary mirror spider assembly.

Let's look at the primary mirror cell first. It consists of an aluminum plate 9 inches square and 0.75-inches thick. It performs roughly the same function as the cross in the U-joint of a car's drive shaft. It is attached to the back plate with two trunnions machined from aluminum which permit it to swivel in one axis by about 10 degrees.

The same scheme is used to attach the plate to the back of the mirror cell on the other axis. Screws threaded into the back plate and springs resting against the back plate and held there by compression oppose each other on each axis. Note that the screws and springs sit between the back plate and the mirror cell, and they never touch the tilting plate. This shows clearly in the accompanying photographs.

The secondary mirror focusing assembly is attached directly to the spider vanes. These vanes attach to the inner of two concentric aluminum rings arranged as a double gimbal. The rings are held together on one axis using two Bendix flex pivots that are stainless steel barrels split in half, which provides both a rotational bearing and a spring loaded restoring force. Because flex pivots are expensive, you can make trunnions similar to those used on the primary cell, with springs resting against screws driven through the telescope tube.

The outer ring is attached to the telescope tube on the orthogonal axis using the same arrangement. Two $^1/_4$-inch diameter aluminum rods running the length of the telescope tube are attached to two of the adjustment knobs. The other ends are threaded and inserted into nuts attached to the inside of the telescope tube. The ends of the rods rest against the sides of the rings, tilting them a few degrees as the rods are screwed in or out of the fixed nuts. The Bendix flex pivots are mounted to force the rings to stay against the ends of the rods.

If you wish to discuss these or other ideas further, feel free to call Trueblood at (602) 323-1268 evenings or weekends.

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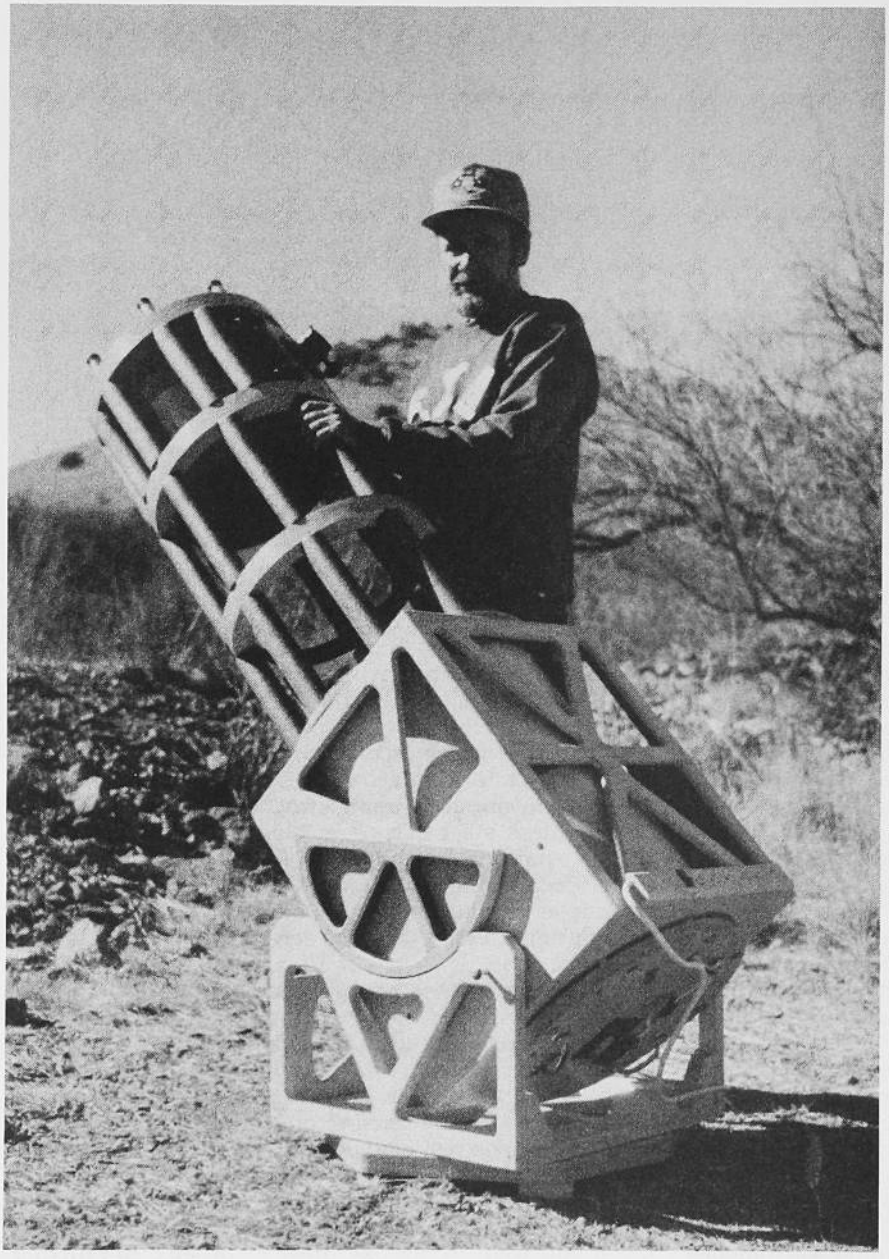
Doing It Right

Creating a Rotating Tube Dobsonian using Computer-Assisted Design and Advanced Woodworking Methods



Author with the "Gatling Gun," By gripping the tubes on opposite sides and twisting, you can rotate the eyepiece around to the most comfortable viewing position.

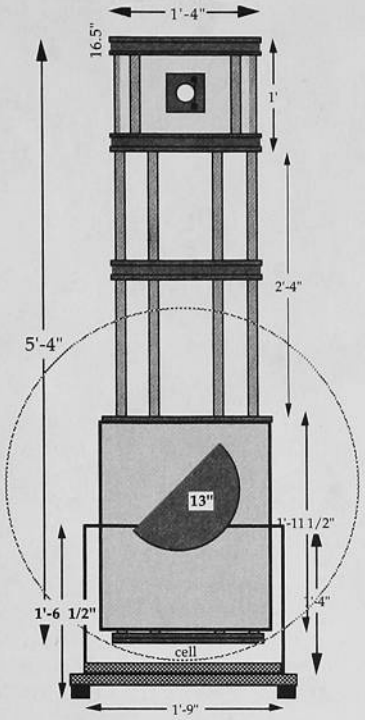
My first affair with astronomy and telescope making ended in 1964 when, as a late-blooming 21-year-old, I decided that spending my nights in a open field was not preparing me for life, especially girls. I sold or gave away most of my equipment and bought a bright red Plymouth Barracuda. I still remember the date and often it appears in my dreams—such are first loves. When my future stepson expressed an interest in telescopes, the desire to build another telescope surfaced. Now that I have a real woodworking shop, more skill, and a lot more money, I set out to construct a really fine instrument.

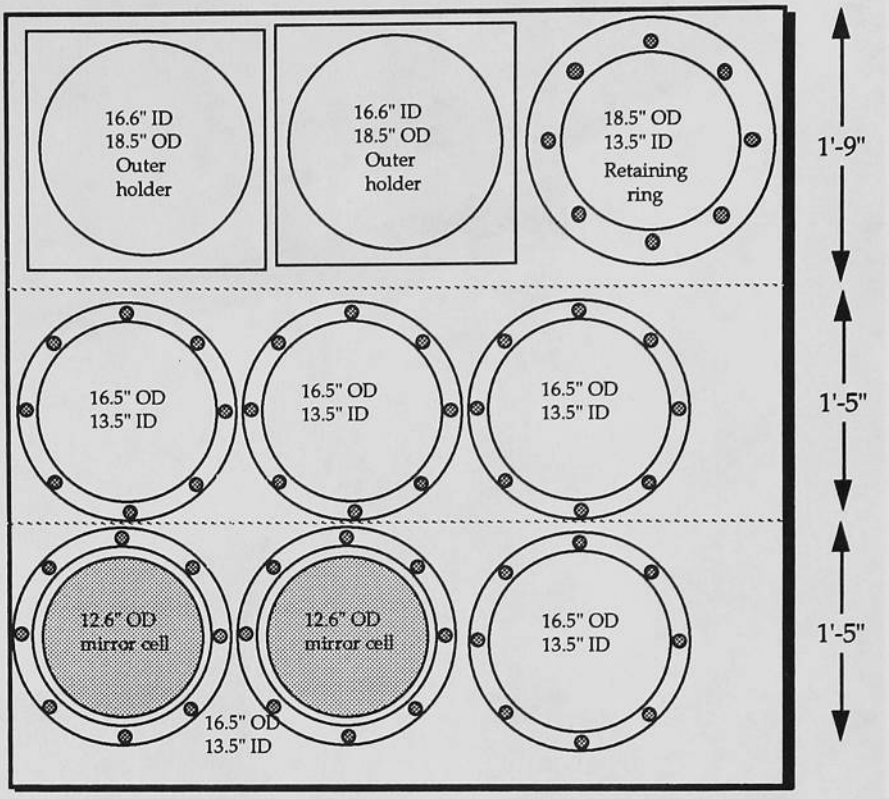
Since a number of years had passed since I last looked at telescope construction, I researched the subject at the library and bookstore and sent for a trial issue of TM. The Dobsonian revolution had occurred without me, and at first I considered copying the existing designs. However, like a lot of TMs, I came up with better ways of executing particular parts. This article is not intended to provide complete construction plans, but rather to present certain component designs and construction methods in the spirit of sharing my experience.

Design

The specific design objectives I had when starting this project follow:

1. A lightweight fixed tube design to maintain collimation. My research indicated that fast f/ratio mirrors were very sensitive to collimation (I planned to use a Galaxy Optics 12.5" f/4.8 primary).
2. A rotating tube to place the eyepiece in a comfortable position for long observations and to accommodate other observers.
3. A secondary/eyepiece cage that would allow precision adjustment of the focal plane for the yet-to-be-purchased eyepieces.
4. Quick set-up in the dark so observing would remain an inviting experience.
5. A mirror cell design to work with the rotating tube, allowing precise collimation adjustments.





Telescope components can be rotated on the computer screen to determine minimum clearances. Dashed line shows rotation of tube holder.

Using a Macintosh computer and MacDraw II, I was able to quickly and accurately complete the design of my telescope. While not a full function CAD program, MacDraw II has advanced drawing features which greatly enhanced the design process. These include drawing to scale, automatic dimension lines (which place the scale readout in the middle of a line), and precision drawing of circles and rectangles which can then be easily moved, rotated and duplicated. Once drawn, objects can be filled with various patterns to represent different construction materials. Another advantage is that portions of a drawing (such as the tube assembly) can be rotated as they would be on the completed scope to determine minimum clearances with other components.

In the past, I'd formulate a project in my head and design the first part in detail on paper. After the first parts were completed, I found that they determined the design of the rest of the parts. In this way, I painted myself into some difficult corners. With the Mac, it was so easy to create and change designs that I completed the entire design before starting. I was also able to lay out all the parts in advance to economize my use of materials. For example, I made the disks for the mirror cell from the center waste of some of the 16.5-inch rings even after allowing for the 1/4-inch kerf of the router bit.

During construction, I printed scale templates of individual parts to have at my side as each cut or hole was made. Once you start cutting up a piece of plywood, it's hard to keep up with what each of the cut pieces will become. As complex as the project was, only one hole was drilled in the wrong place — far better than my usual performance.

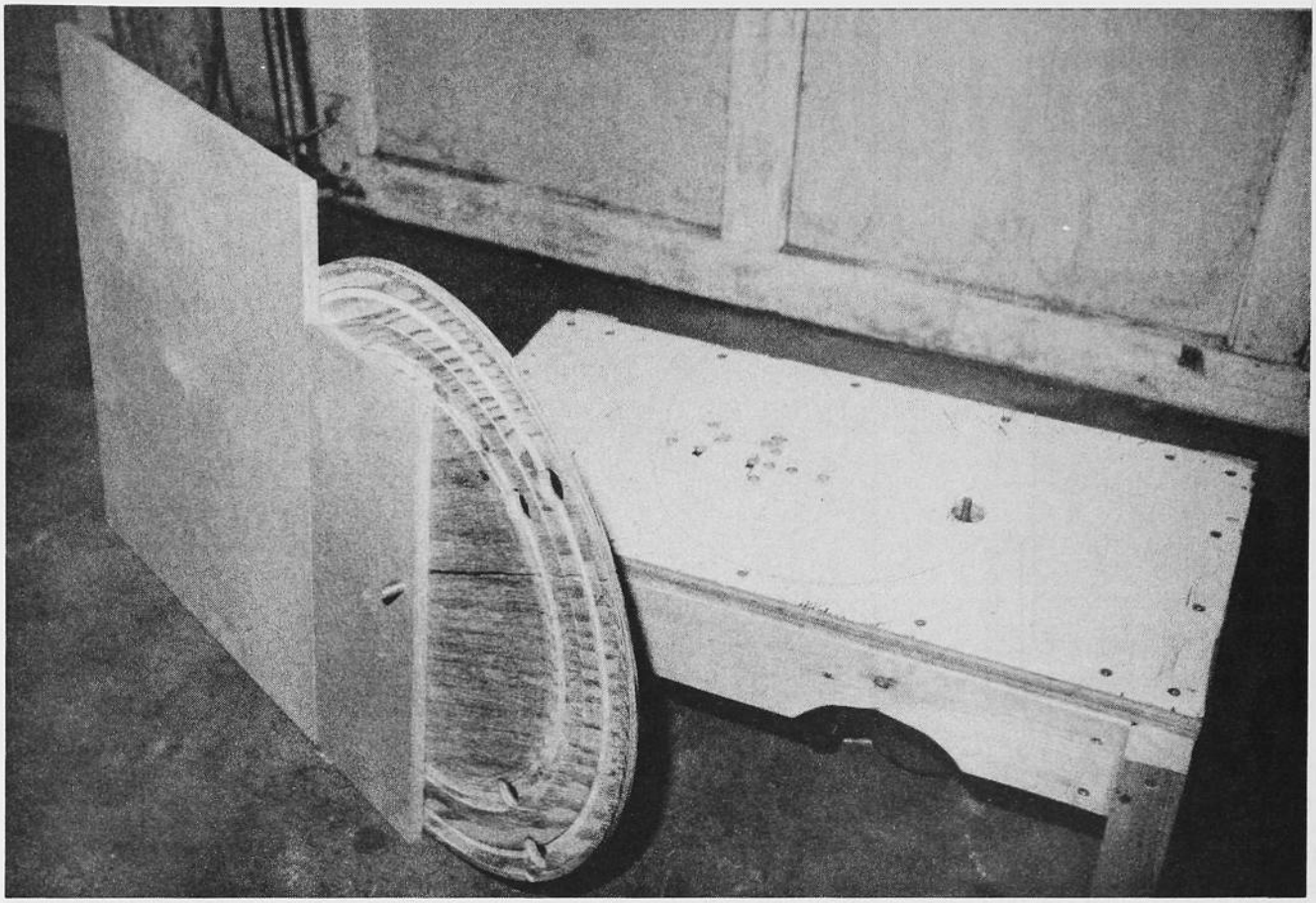
I found myself using the computer as an extension of my thought process — "Is this thick enough? Can I put 2 T-nuts that close together? What happens if I move the push bolt to the inside position?" The ability to easily alter the design and reprint it is a great advantage over plans drawn by hand. Another advantage was accurately determining bolt lengths so I could purchase exactly what I needed.

Use computer graphics to make an efficient cutting plan for the telescope parts.

Component Construction

Rotating Tube Assembly I could not come up with a design I liked for a rotating secondary cage so I designed a skeleton cage tube assembly formed with eight 1" O.D. aluminum tubes in parallel alignment with equal spacing around 8 plywood and Styrofoam sandwich rings. The 1" O.D., 6-foot tubes are sold as shower curtain rods and have a bright finish. Cost is just $3.45 each at a local hardware store as compared to an industrial metals company's price of $28 for 12 feet of 1 1/4- inch tubing without the finish. From *TM#44*, I picked up several critical suggestions from David Kriege's article — large altitude bearings, Wilsonart #4552-50 Ebony Star, and Sequenia's Glass Board, plus an important rule of thumb: stiffness is proportional to the cube of the thickness.

Cutting the Rings. *TM*#26 contained an article on finishing cardboard tubes that included a description of cutting circular rings of plywood with a router table. My first project was to construct a simple 12x20-inch router table with the router inverted on the bottom side at one end of the table. A 1/4-inch straight carbide bit with a 1-inch cutting surface protruded upwards. By drilling vertically aligned 3/8" holes toward the other end of the table, I could produce the correct inside and outside dimensions of the rings. Measure from the center of the 3/8" hole to a cutting flute of the carbide bit that points back at the bolt for the out-



Router table and carrier shield. On the shield's center bolt is a spacer of scrap plywood that positions one of the rocker box side boards to create arcs in the side boards for the altitude bearings to rotate in.

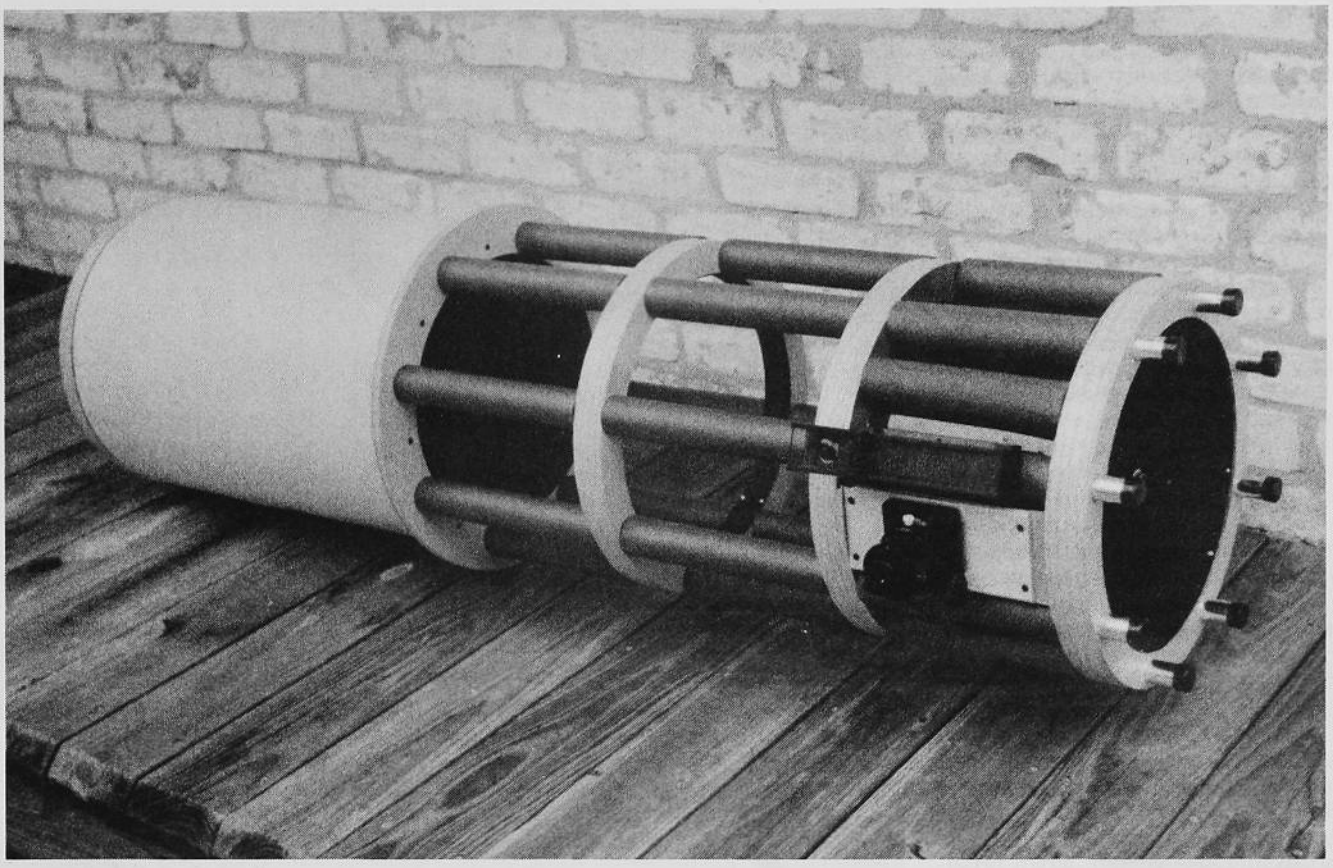
side dimension and measure to a cutting flute pointing away for the inside dimension.

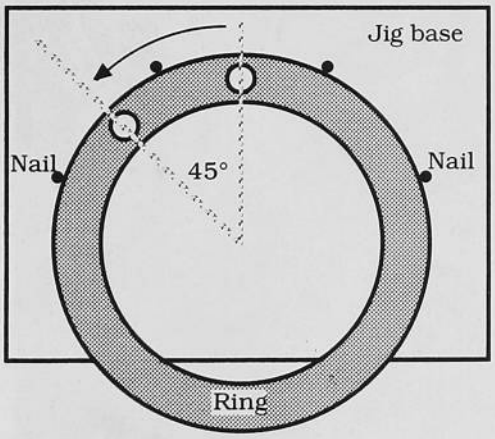
For precision and safety, I cut a solid circular disk of scrap 3/8' plywood that was several inches larger than any ring to act as a carrier and a protective shield. The baltic birch ring pieces were first cut square on a table saw (about one quarter of an inch larger than the final ring dimension). I drilled a 3/8-inch hole in the center (found by drawing a line across the diagonal corners) and passed a 3/8"-bolt through the shield disk and the ring piece. Next, I hammered four wire gauge 1" tacks through the shield disk into the ring piece, locking them together. Tacks hold very well and the tack holes are easily patched later.

My Black and Decker router has a screw mechanism to adjust bit depth which allows me to put the shield/ring/bolt combination in position on the router table before starting the cut. If your router is not easily adjustable, then it must be "on" with the bit at cutting height as you lower the combination into position. Use great care and be sure to wear protective eye goggles. The direction you rotate the shield/ring combination does not matter when cutting into solid wood; however, taking a small cut off the inside or outside edge of a circular ring does require rotating the wood into or against the cutting direction of the router bit. Otherwise you will experience "kickback" or jamming the wood into the bit, causing the bit to break. Save the corners from the ring piece for use as reinforcements in other parts of the design or in another project.

Foam Core/Plywood Sandwich Construction. To reduce weight at the secondary cage and produce sufficient rigidity, I bonded Styrofoam between layers of baltic birch — the closest wood will ever come to aluminum. Baltic birch comes in 5x5-foot sheets and is a Russian product with 9 plies in the 1/2"-inch and 13 plies in the 3/4"-inch. All the plies are solid, good quality stock without the usual plywood voids. I had a problem finding a glue that would dry against the closed cell foam and not dissolve it but found a construction adhesive called Contech PL-400 Subfloor Adhesive. After placing the adhesive between the foam and the wood, quickly separate the two for about 2 seconds before pressing them back together in final alignment. This exposes more of the adhesive to air and results in rapid drying — as quick as 10 minutes.

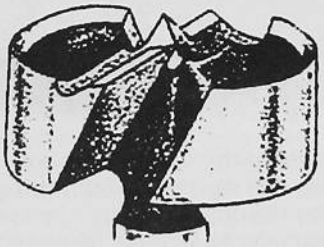
Attempts to drill the 1-inch holes through the sandwich resulted in the wood at the bottom of the hole of the upper ring splitting because of little resistance from the foam. The split debris would then rip the foam in that area. The solution was to drill the holes in what would be the upper ring before gluing up the sandwich. Then using the holes in the upper ring as a template, drill through the foam and the lower ring. As a woodworker, I cringe when I read in *TM* that people use spade bits to drill large holes in wood. For extremely smooth holes, I use a Forstner bit that has a cylindrical head and a cutting bar across. Forstner bits can be more than half off the edge and still track correctly and can create flat-bottomed blind holes if desired. Another use is to countersink T-nuts — use one Forstner bit the size of the pronged disk to drill a





Often, the first step in a project is creating a jig to make construction easier and more accurate. In this jig, plywood rings rotate on a fence of nails to position 8 holes for drilling. See text for more information.

The completed skeleton tube assembly has formica enclosing the mirror end and pipe insulation placed over the exposed aluminum tubing.



The right tool for the job. Use Forstner bits to create smooth, accurate holes.

3/32"-inch deep hole, and another Forstner bit slightly larger than the threaded shank of the T–nut to drill the rest of the hole.

Indexing Drill Jig. To accurately space the eight 1" holes equally around the plywood rings, I created an indexing drill jig. To make one, clamp a scrap of plywood large enough to support more than half the diameter of the plywood rings to the table of the drill press to act as the base. A plywood ring was positioned under the Forstner bit and on top of the jig base so that the bit was centered across the width of the ring, and the first hole was drilled. With the bit lowered into the hole, hammer four 6D finishing nails into the jig base tight against the arc of the ring. After the nail heads were snipped off, the ring can be rotated smoothly against the fence of nails.

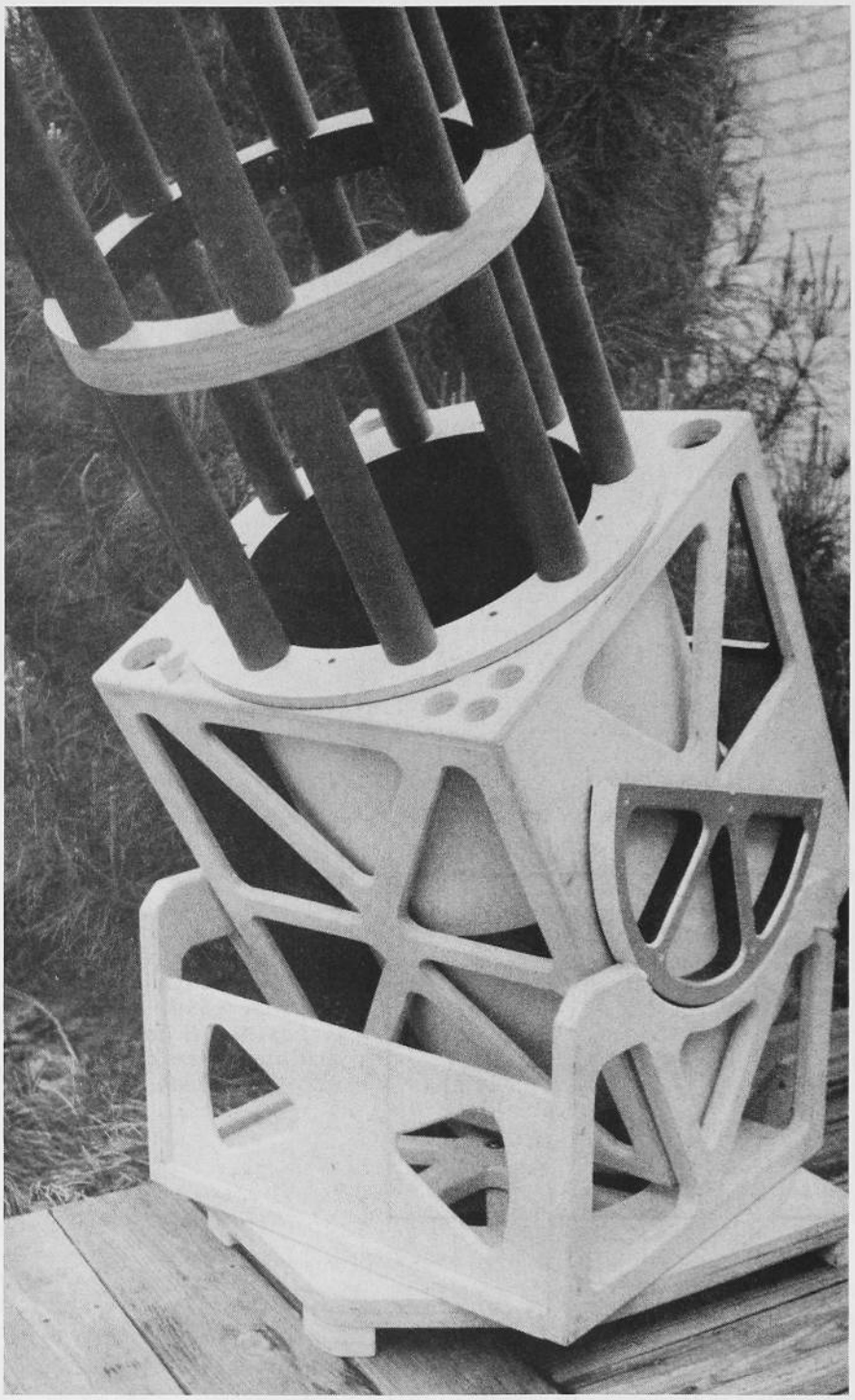
I made a mark 45 degrees from the ring's first hole and drilled a shallow hole into the jig base. I put a short scrap piece of 1 - inch tubing through the first hole and into the jig's hole, and then proceeded to drill the second of eight holes. By transferring the scrap piece of 1 - inch tubing to each newly drilled hole and rotating (indexing) over 45 degrees, I worked my way around the ring until all eight holes were drilled. Even if the 45° measurement is slightly off, the only effect will be that the spacing between hole #1 and #8 will be different from the others. No problem if the #1 holes in all rings are aligned to each other and none of the rings are flipped over from the orientation (same side up) as when drilled.

I had a tremendous feeling of satisfaction as I guided each tube through the eight consecutive rings spread over 6 feet with a near per-

fect fit. The resulting skeleton structure weighed only 8 pounds and was extremely rigid. If your drill bit makes a hole that is slightly too small for the tubing you'll need a hole sander. You can make one out of a wooden dowel 2 to 3 inches long and the same diameter as your drill's chuck capacity. Sand a flat spot 1 to 2 inches down its length deep enough that the heads of small tacks are below the circumference. Cut a piece of coarse sandpaper (a piece of cloth backed sanding belt is best) as wide as the flat spot and longer than the circumference. Put a small bead of glue on the flat spot and tack one edge of the sandpaper to the dowel so that the sandpaper wraps around the dowel away from the direction of rotation of the drill. The other end is left to flap free. Rub the spinning sander around the inside of the drilled hole to gradually enlarge it.

Enclosing the Skeleton Tube. To finish the tube design, I rolled some of the excess #7181 Formica laminate (you have to purchase an entire 4x8-foot sheet and mine cost $65!) around the bottom half of the skeleton tube to act as a light baffle and to increase rigidity when pushing on the end while guiding. Even a completely enclosed tube would be stronger and lighter than a comparable size Sonotube. I used contact cement on the edge of the rings and matching strips on the laminate. I would suggest using epoxy so adjustments in position of the laminate can be made as it is wound around the skeleton tube. Wire gauge nails or tacks can be used to secure the ends. Heat the nail heads with an electric soldering iron until the laminate melts slightly and then lightly hammer the nail head flush. This will prevent splitting the laminate.

Interior Light Baffle. On the inside of the bottom half of the skeleton tube, I lined the interior surface of the plywood rings above the primary mirror with 10 mil plastic sheeting. To absorb and scatter reflections, I used #80 grit sandpaper to rough up the surface of the plastic before spraying it with flat black paint. The same method applies to line the secondary cage. To make holes for the screws in the plastic sheet, I used a narrow point soldering iron to melt the holes. A drill bit often tears the plastic as the plastic spirals up the bit.



The weight of the tube carrier box, altitude bearings and the rocker box has been reduced by nearly half by aggressive removal of triangular sections. An oversized ring rides on Teflon pads on the top surface of the carrier box. Note the eyepiece storage holes on the corners of the carrier box adjacent to the oversized ring.

Finishing Touches

It's good practice to assemble a unit without glue first to check the fit of all the parts. Use bee's wax (toilet bowl seal from a home improvement center) on the screw threads for easy driving and removal. Power screw drivers are wonderful for this operation. Apply wood stain before using glue since any squeezed out glue will seal the wood's surface, preventing the stain from reaching the wood. Let squeezed - out glue droplets "liver" or turn into rubbery balls before picking them off with your fingernails. Glue runs should be wiped off with a damp cloth quickly.

Selecting a Wood Finish. I wanted a wood finish that would dry fast and provide superior resistance to moisture so the wood wouldn't

warp. I found two that work great: Deft Wood Armor and 3M Scotchgard Wipe - On Poly Finish. Wood Armor is a water based varnish that is milky white in the can but dries clear. Using a foam brush, I put a coat on one side of a part and dried it in a few seconds with a hair dryer. Using this approach I could put two coats on both sides of a part and dry it in under 5 minutes or paint a number of parts in one session. I could continuously paint until all parts were double coated. Although local home improvement centers carry Deft products, I had to order the Wood Armor through the mail. Wrap the foam brush in plastic wrap between usages, and it's immediately ready to use again even a day later.

3M Scotchgard Wipe-On Poly Finish is another product providing fast drying protection and is available at discount stores and home improvement centers. It's wiped on with a soft cloth, which makes it very easy to produce a bubble - free surface. I know it's extremely resistant to water and other liquids as I used it successfully in remodeling my kitchen cabinets. My only objection is the fumes.

Edge Finishing on Exposed Rings. The upper rings of the tube assembly were all foam/plywood sandwiches, and their outer edges needed to be covered to both protect the foam and to finish them (the inner edges are covered with the black painted plastic). Baltic birch is so solid that it can be successfully sanded and varnished for a good looking edge treatment, but it still looks like plywood. The solution is a strip veneer called Edgeply or edge banding that comes either $^{13}/_{16}$ or 2 inches wide and in 8-foot lengths. It is available in many different wood patterns with or without heat–set adhesive backing.

Birch Edgeply is a good choice since it is fine grained and has little color. The heat–set is good for quick application of large amounts of edging, but the iron (for pressing clothes) has to be used very carefully on foam or the foam melts, leaving the Edgeply unsupported. Don't apply the Edgeply until the sandwich rings are in their final position as the force necessary to move them sometimes compresses the foam and will wrinkle the Edgeply. It was difficult to spiral a strip all the way around a large ring and get the ends of the Edgeply to match up, so I used woodworkers' glue on the wood edges to allow adjustment before the glue dried. Straight pins and masking tape can be used to secure the ends. Then trim the excess Edgeply by guiding a sharp knife held down against the flat surface of the plywood ring and bevel the edge by sanding parallel to the edge at 45 degrees.

Weight Reduction of the Mounting. Many of the telescopes that I've seen in *TM* have large slabs of plywood for the rocker and mirror boxes. Much of the wood could be cut away to reduce weight. I cut out triangular sections that left spoke-like patterns (with spokes 1to 2 times wider than they are thick). Baltic birch allows this idea to be taken to an extreme — my rocker box was reduced from 32 pounds to 18 pounds! The total weight reduction was from 127 to 95 pounds, or 25%, and much of the remainder is optics and hardware that could not be reduced. Use a Forstner bit to make the round points of the triangles and cut away the triangles after trial assembly. Use just a few screws to hold the unit together in alignment, depending on glue to provide structural strength. My tube carrier box has no fasteners other than glue and the rocker box only has 8 screws.

Round Cornering. The appearance of your wooden parts can be improved dramatically by round cornering the edges. Ordinary plywood should be done by hand just enough to smooth the edges. On solid wood or baltic birch, this is an easy job with a router and $^1/_8$" or $^1/_4$"-inch radius round-over bit. Make sure you plan ahead for screw heads, even if countersunk, to be far enough away from the edge to clear the bit.

Performance

Setup is simple since the tube is a complete unit. Often I can simply insert the tube and I'm ready to observe. The mirror cell holds its collimation to the point of passing the autocollimator test even after long trips in a trailer. The rotating tube assembly allows a comfortable eyepiece position wherever the scope is pointed. The ability to adjust the focal plane at the focuser allows maximum use of the limited $1^1/_2$" inches of travel of the Tectron low profile focuser with the eyepieces and accessories I use. My 20mm Nagler and a Paracorr coma corrector require the closest inward focus and I left an additional $^1/_{16}$ inches inward travel and $^3/_4$-inch outward travel over my furthest required focus. It would be difficult to obtain this precision positioning by trail–and–error cutting of the tubing. About the only negative to this design (and for some it might be a big one) is the large tube size needed for a 12.5-inch. It requires a trailer or van to transport it.

The combination of the Nagler eyepieces and the Paracorr create beautiful pinpoint images to the edge of the field rather than the small central "sweet spot" I've seen with other eyepieces. What sold me on Naglers was a friend's describing the view as being like sticking your head out of a porthole and moving it around in order to see everything. The only problem is the cost ($600 for a 20mm Nagler and the Paracorr at mail order discount prices) and the nearly 3 pounds of weight that this combination places at top of the scope.

When I do build another scope, bigger I'm sure, I'll combine the rotating tube with the Serrurier design — attaching the Serrurier tubing to a lower rotating tube section containing the mirror. This would be a variation of the classic mirror box design and would allow easier transporting because of the reduced tube size and ability to leave the mirror in the tube.

If I built another it would take about half the time since now I know where to find the parts, what jigs are needed and the construction methods. If you have any comments or questions, please feel free to write.

Ed Stewart
11615 River Oaks Trail
Austin, TX 78753–2820

Sources

Styrofoam
Local art and crafts stores. They stock it in both slab form and precut rings.

Forstner & Router Bits
As well as T–nuts and other good stuff at:

Woodworker's Supply of NM
5604 Alameda Place NE
Albuquerque, NM 87113

Woodworkers' Store
21801 Industrial Blvd.
Rogers, MN 55374–9514

Leichtung Workshops
4944 Commerce Parkway
Cleveland, OH 44128

Baltic Birch Plywood
Local hardwood stores (not home improvement stores or those selling construction grade wood). Or call Allied International for a source near you (617-241-7970).

Western Hospitality Promotes Best Texas Star Party yet!

The Texas Star Party celebrated its tenth year at the Prude Ranch in Ft. Davis, Texas, the week of May 12. Six hundred and fifteen participants converged on the darkest skies in the continental United States for what proved to be the best Texas Star Party yet. Although bad weather nuked the TSP the last two years, this year's TSP enjoyed eight nights of good observing weather, including five consecutive, totally clear, dew-free nights.

Everyone's stay at the ranch benefited from improvements made this year. The air conditioning in the auditorium worked so well that some people even complained of being too cold. (Outdoors, of course, people baked in the relentless Texas sunshine!) The availability of inexpensive, on-site ice eased the daily runs to Fort Davis for ice chest refills. And during the day the ranch's attractive indoor swimming pool and newly opened ice cream stand were popular hangouts for beating the heat.

Most important, however, the weather proved extremely hospitable for astronomers eager to push their telescopes to the limit under ideal skies. In a sense, so many clear nights were almost too much of a good thing. As night after clear night passed, continuously clear skies were beginning to take their toll. Tom Clark from Tectron Telescopes openly wished for clouds so he could catch up on sleep without suffering guilt from missing a clear night sky.

Changes Evident In Observers

This year's TSP crowd seemed to be more mellow and friendly than in previous years. Gone were the often militant gatherings of last year when lightning displays frayed tempers. Continuous clear sky went a long way toward promoting telescope hospitality at TSP.

That long, tall "Texan" is Hale Allen. He's actually from Arkansas, and he's standing beside the 10-inch Dob with a mirror that he ground himself.

For several years, subtle changes have been occurring in the demographics of TSP attenders. Last year, for example, the emergence of women as a force in amateur astronomy was quite evident because some of the largest telescopes at TSP were owned by women. Furthermore, as the core of regular TSP attenders has aged over the past ten years, their families have also grown. This year, the next generation of observers made its debut under the dark Texas skies, as two dozen children were also in attendance with their astronomer parents.

The children's presence was a welcome answer to a question openly discussed at last year's Star Party: Where is the next generation of amateur astronomers? We had not seen younger observers entering the ranks as we "baby boomers" aged. Now the next generation was finally joining us.

My own six-year-old son, Jeffrey, was one of the celestial youngsters enjoying for the first time skies free of light pollution. Indeed, Jeff took to the sky so well that he refused to go to bed until he could see that all of Scorpius had risen above the mountains.

As the galaxy-hunter's paradise between Leo and Virgo passed overhead, two divergent sides of amateur astronomy observed in side-by-side harmony at TSP. Visual observers brought an abundance of large-aperture Dobsonians. At the same time, the electronics explosion in amateur astronomy was evident as scattered between the visual giants were the red glows of LEDs and CRT monitors. The two observing factions are usually at odds with each other, but the quiet, almost relaxed coexistence of visual and electronic observing pays tribute to the magnificently clear skies at this year's TSP.

Programs Span Diverse Topics

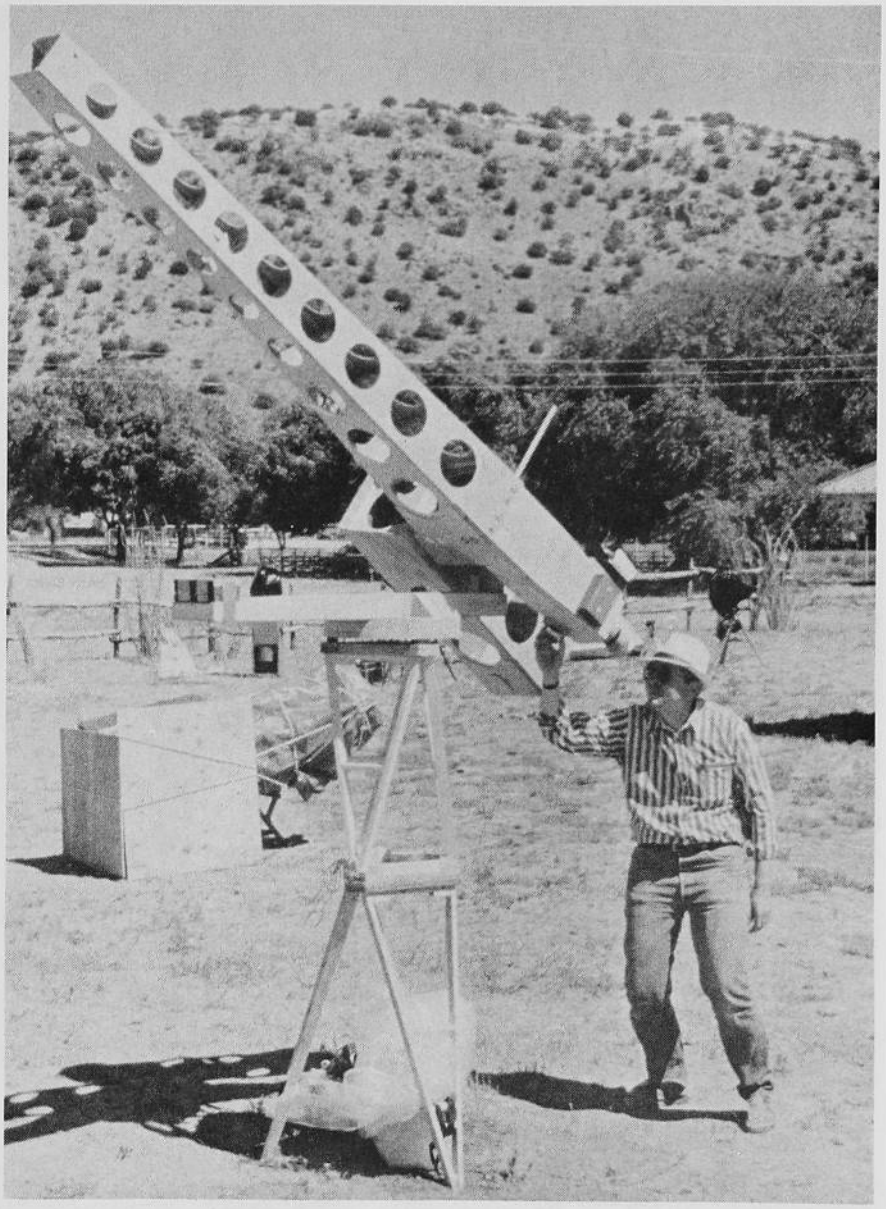
Contrasting the traditional deep-sky nature of the Texas Star Party, there was a large pool of comet hunters present. Boasting a total of 17 discoveries between them were Howard Brewington (2), David Levy (11), Brian Skiff (3), and Clyde Tombaugh (1). Prolific comet observer John Bortle and high-resolution planetary observer Steve O'Meara rounded out the well-known group of sharp-eyed shallow-sky observers.

Organized daytime TSP activities centered on lectures by guest speakers. The many excellent presentations included astronomical computing seminars, equipment and observing techniques, astronomical databases, photometry, CCD photography, satellite observing, and much more. Evening keynote speakers included well-known astronomical personalities and experts in a variety of fields.

Pluto discoverer Clyde Tombaugh returned for his third TSP visit. Having previously related his story of the Planet X search, this time Clyde discussed his scientific accomplishments in the years after his famous planetary discovery. Few people knew that Tombaugh was heavily involved in the early American missile and space exploration program shortly after WW II.

The wonder of Tombaugh's Pluto discovery 51 years ago is often lost to modern generations jaded by space-age celestial revelations. For a brief moment the next evening, the excitement of that turning point in astronomy was revived by an encounter between my son and Clyde Tombaugh. Clyde was enjoying the cool relief of sundown on the steps outside his cabin when Jeffrey and I passed by. After we said hello, Clyde and Jeff enjoyed some child's play together. I then told Jeff this was the man who found Pluto, the little planet in the books I often show him. After a brief puzzled look, a wide-eyed flash of excitement crossed his face as the significance of that became clear even to a six-year-old mind.

John Bortle revived astronomical history with a review of the Great Comets through the centuries. He sized up the observing experience of the audience by asking for a show of hands by those who saw which comet. For Halley (1986), the whole room responded; for West (1975), about half; for Bennett (1970), a handful. When he got to Comet Arend-Roland (1957), I was shocked to find mine was among only four hands still raised!



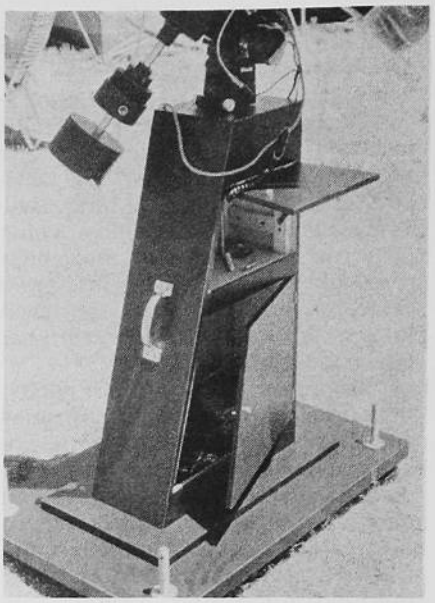
John Gustinis brought his ten-foot, 55-pound 8-inch f/36 anastigmatic Schiefspiegler. The tube is constructed of 1/8-inch plywood.

The head of the AAVSO, Janet Mattei, fascinated the TSP audience with details of how ordinary backyard amateur observers are helping conduct exotic X-ray and ultraviolet studies of cataclysmic variable stars. AAVSO members monitor the activity of selected cataclysmic variables and alert authorities when these objects flare up. This warning is used to bring orbiting observatory satellites to bear on these strange objects when they are active.

A thought-provoking discussion about the controversy surrounding the theoretical links between relatively close galaxies and apparently far-away quasars was presented by Jack Sulentic, a former colleague of Halton Arp. Sulentic presented a balanced account of the issue, showing that as much as we know about the universe, there are still areas of deep mystery.

Midwest Shows ATM Ability

Although TSP is billed as an observer's event, it nonetheless has attracted a small following among telescope makers. The twenty-four entries in this year's telescope display spanned the range from first-time telescope makers to experienced hands with more advanced and innovative versions of designs they had shown in previous years.



Observing Comforts

Nothing beats a chart that's illuminated (at Olin Atkinson's observing desk), an eyepiece easy to reach (in Jerry Lindeman's pier), or the wind that doesn't blow down the back of your neck (when you're warm inside Joe Gafford's portable dome).

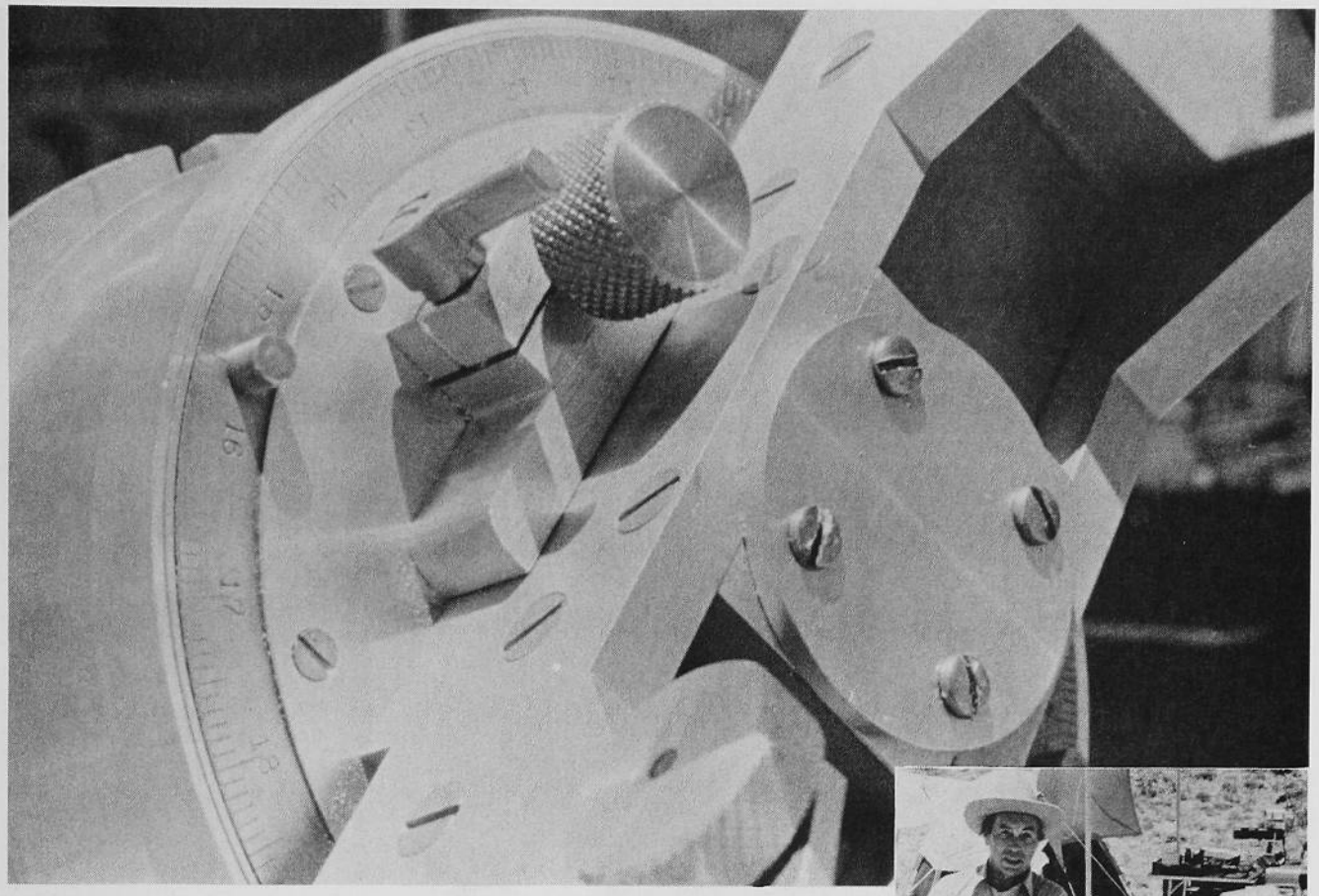
Curious crowds of telescope enthusiasts browsing among the several-hundred instruments set up at TSP allowed the owners to show off their telescopes.

After days of passing by a small, empty equatorial mount, I finally saw the instrument it carried. An elegantly simple white box structure held a 6-inch f/12 tilted-component Yolo telescope built by James Mulherin of the Iowa City Amateur Astronomers. James related that the optics took 40 hours of computer time to design.

Richard Poletti from the St. Louis Astronomical Society displayed a sturdy 13.1-inch f/4.5 open-truss Dobsonian. His upper telescope support truss attaches to the mirror box of the scope by simply slipping into a conduit which has been bent to the appropriate angle.

Two attention-getting hand-crafted instruments were displayed by Fr. James Fahey from Burnett, Texas. He used a $35 Bausch and Lomb projection lens as the objective of his aluminum 4-inch f/3.8 refractor. After having the fork mount cast, he machined his own tripod and wedge and engraved the setting circles. A pair of 30-year old 3-inch f/3 objective lenses was also transformed by Fahey into fine brass binoculars. Three mirrors substitute for prisms in his design, which sits atop a handsome tripod made from ordinary conduit tubing.

Steve Watkins from the Fort Bend Astronomy Club in Texas showed his hefty 17.5-inch f/4.5 Newtonian set on a German equatorial mount. With its large box-shaped primary mirror housing, this monster looked at first glance like a Dobsonian telescope that had



Fine machining makes Fr. James Fahey's fork-mounted refractor a pleasure to behold. The objective is a 4-inch f/3.8 B&L projection lens.

been transplanted to an equatorial mount. Closer inspection quickly showed that a lot of thought had gone into the design. Steve's approach to this telescope project can be summed by the small plaque attached near the eyepiece which reads "M. O. A. T." I asked and Steve explained that this stands for "Mother Of All Telescopes."

To prevent the German mounting from placing the eyepiece in uncompromising positions, M. O. A. T.'s secondary cage independently rotates on 18 Teflon pads. To allow continued observing near the ultra-humid Texas Gulf coast, Steve added two commutator rings that transfer 12 VDC power via roller bearings to anti-dew devices on the rotating portion of the telescope. The large box structure surrounding the primary retards dew formation on the main mirror. To cool the primary mirror after assembly, the primary box features filtered cross ventilation.

The burden of storage and transport of the 17.5-inch scope is eased by the removable secondary cage which attaches to its support truss with ball-and-socket joints. The truss tubes themselves in turn attach to the primary box with cam locks.

Improving on the manually driven remote-collimation jack screws that he showed last year, Steve added three remote-controlled electric motors which refine the tilt of the primary while he looks through the focuser. This reduces the task of collimating his oversized telescope to a quick one-man job.

Chuck Shaw from the Johnson Space Center Astronomical Society has taken a different approach to collimation. Instead of looking through the focuser and working the mirror by remote control, he manually shifts the mirror while remotely looking through the focuser. A five-inch television monitor rides piggy-back atop his 14.5-inch f/5 Dobsonian while a tubing bracket holds a television camera to the focuser. This handsome telescope features a 2-inch-thick mirror and two-piece, rotating Sonotube construction. The break-apart rocker box rides on a Poncet platform for star tracking.

Combination chart holders and observing desks continued to show personal refinements. Olin Atkinson of the Texas Astronomical Society fashioned his out of plywood. Olin uses tempered glass to cover and hold his sky charts. To keep the design simple yet stable, Olin mounts his chart desk on a collapsible Black and Decker Workmate.

Joe Gafford of the Denver Astronomical Society carries his observatory with him. He fabricated his seven-foot-diameter portable dome out of Cordura Nylon and PVC pipe with only a $200 investment. The dome takes about

James Mulherin stands beside his 6-inch f/11.7 Yolo telescope. Mulherin describes the techniques he used to make the optics in this issue of TM.

a half hour to set up and rotates on its own wheels.

Showing that women are also very much in the telescope-making game, Monica Coleman of the Austin Astronomical Society crafted her classical 8-inch f/8 Dobsonian for under $200. The scope features a rotating tube and Motofocus drive on the focuser.

Situated near the entrance of the Texas Star Party was an 8-inch f/36.2 anastigmatic Schiefspiegler assembled by John Gustinis of the Las Cruces Astronomical Society. The telescope features a spherical primary and a spherical 4.5-inch secondary mirror. While it stands 10 feet high, it weighs only 55 pounds. The lengthy tube was made from $^1/_8$-inch plywood and lightened by the addition of nearly 40 large holes, giving this eye-catching instrument the appearance of a missile launcher.

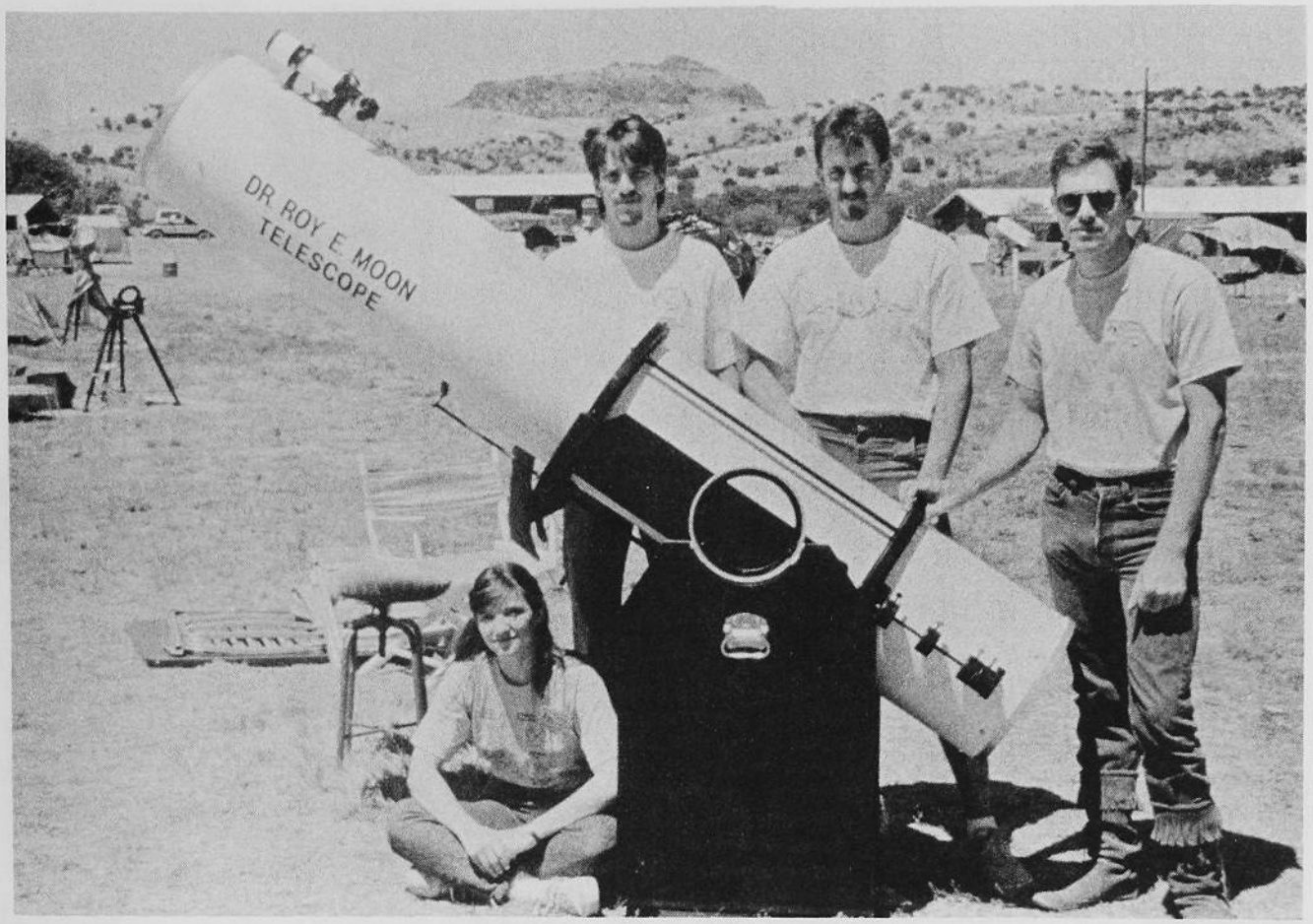
One of the simplest yet quite useful observing items was a light stick for providing a light source for checking axial convergence with an autocollimator. Looking much like a short electronic fishing rod, the light stick carried a tiny LED on the tip of the pole.

An 18-inch f/5 fork-mounted Newtonian assembled by Douglas and Myrlas Matthews from Batesville, Arkansas, showed an unusual spider for the secondary. Two equally curved vanes arcing away from the center canceled spider diffraction in the scope's image. After grinding their own mirror, the Matthews used $1,000 worth of metal in the fabrication of the scope's massive mounting, which features an 18-inch Byers drive gear.

It isn't often that you get to look through a telescope used to discover a comet. In the case of Howard Brewington, currently with the Alamagordo Amateur Astronomers, you can do this twice. Brewington now has both of his comet-discovering telescopes mounted piggyback on a single Dobsonian mount. Howard ground the mirrors on both the 8-inch f/4.3 and 16-inch f/4.5 telescopes. He discovered his first comet with the 8-inch and his second with the 16. Brewington has optimized the design for efficient comet hunting. The Dobsonian mount swivels easily in azimuth on 12 rollers. The mount also has audible limit switches to signal when a specific azimuth and elevation have been reached during a comet sweep. Different eyepieces are stored in a holder next to the focuser.

Walter Farrar, also from the Alamagordo Amateur Astronomers, returned this year with the Mark II model of his armillary sphere equatorial setting circles on the alt-az mount of his 17.5-inch f/4.5 Dobsonian. Similar to the armillary sphere system he displayed last year, the Mark II features an improved sidereal clock for driving the right ascension scale. The assembly was also mounted in a more compact fashion against the mount's rocker box. The circles can be adjusted from 25 to 45 degrees latitude and are mechanically linked to the mount by a chain drive in azimuth and a coupler in elevation. Walter says the inexpensive device allows him to navigate around the sky very easily because the circles show him which way to move the telescope.

An innovative item that was not part of the telescope display but will surely become popular in the future



Bob Kirschenmann and members of the St. Louis Astronomical Society pose beside their 10-inch f/6 Dobsonian that honors Dr. Roy E. Moon.

was Peter Wraight's Triple Reference Interpolator Finder. The device operates like a wide-angle Telerad finder, but by using the appropriate template for the object desired, it projects three spots against the star background. The left and right spots are aligned with known bright stars. The center spot and the telescope's field of view are then automatically aligned with the desired deep-sky object. Wraight has applied for a patent for his simple and foolproof finder system.

Large Aperture and an Amazing Eyepiece

This year's Star Party presented me with a new observing situation. While I brought my C8 telescope, I never once looked through it. The availability of large-aperture instruments and the willingness of their owners to share the view made for an irresistible distraction.

Tippy D'Auria, coordinator of the Florida Winter Star Party, took advantage of the large telescopes as he commandeered Tom Clark's 25-inch Dobsonian and proudly showed off the prototype 35mm Panoptic eyepiece given to him at the Winter Star Party by Al Nagler. The Panoptic is a new eyepiece design that features an ultra-high contrast, 68-degree apparent field of view with about five times better edge correction than other wide-field TeleVues. Along with these advantages, the Panoptic has an amazing 26mm eye relief. This design will be released soon by TeleVue.

I have become accustomed to the wonder of views through TeleVue and Nagler eyepieces, but I wasn't prepared for my first look through Tippy's Panoptic eyepiece. To put it in simple terms, the view knocked my socks off. The magnificent Omega Centauri cluster no longer looked like a lump of rice pudding, but instead looked like it had holes torn in its surface. The added contrast provided by the Panoptic eyepiece allowed me to see details I had never seen before. After I installed a UHC filter and turned toward the Veil Nebula, the Panoptic showed the streamers of NCG6960 and 6992 like jet airplane contrails. It is clear that the Panoptic eyepiece is going to be a winner!

Another exciting object easily seen through the forest of huge telescopes at TSP '91 were the multiple images of a quasar in Ursa Major produced by a gravitational lens. Steve O'Meara introduced observers to this seventeenth-magnitude object and noted that at the time perhaps only two dozen observers had seen it visually. An exclusive club indeed. Observers wishing to expand the limits of their telescopes will find this object plotted in the middle of Chart 45 in Uranometria 2000.0 as Quasar 0957+561A/B.

Next year's TSP promises to push the visual frontiers of amateur astronomy even deeper into space. Make your plans to attend the event from April 26 to May 2, 1992. Come on down and we will save a real Texas "Howdy!" just for you.

Robert Reeves
520 Rittiman Road
San Antonio, TX 78209

RTMC '91

It's Thursday night before Memorial Day weekend and I'm filled with excitement and anticipation. I've wrestled baggage and boarded a California-bound flight for a great long weekend at the Riverside Telescope Makers Convention.

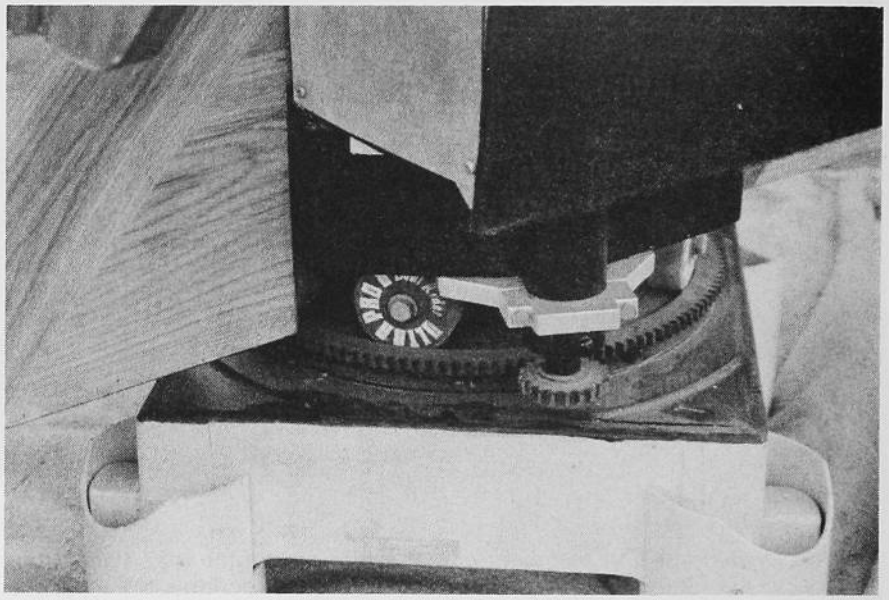
When I fly to Riverside I try to travel light. Driving always means that I can haul back whatever goodies I find at the swap meet, and the kind of goodies I buy are difficult to carry on an airplane. The problem, you see, is that I'm after glass.

On each of my five previous trips to Riverside I've snagged glass, glass to work into precision optics. In Canada, where I live, glass is relatively tough to find because there isn't much of an optical industry. But glass flows like water in California. I love it!

Brilliant Venus shines through the airplane window, and I gaze long and hard at a few stars that lack the usual twinkle we see from the ground. Those twinkle-free stars recall the hours I've spent hunched over telescope mirrors, tweaking figures to focus light as perfectly as possible. Imagine what celestial images would be like at 30,000 feet!

As the plane sweeps over Los Angeles I marvel at other lights, lights on the ground. Flying into LAX is overwhelming: bright light extends to the horizon. No celestial light other than the Sun can stand against the glare of lights in the LA basin. I am surprised that the skies over Big Bear are as dark as they are considering the proximity of Los Angeles. I drive into Big Bear's Motel 6 at 2 a.m. local time, 5 a.m. body time, and see a familiar vehicle in the lot.

At daybreak, I'm surprised at how energetic I feel. Must be that crisp mountain air and the anticipation of things to come! And then I step out onto the motel balcony and see Denny and Kevin Medlock and their kids in the parking lot. After exchanging a year's worth of hugs and hellos, we drive to McDonald's for breakfast. Vance Chin and Ron Story are with us, and while I wolf down a couple of Egg McMuffins with Canadian bacon, we all talk about telescopes, CCDs, taxes, the California drought, and more CCD stuff!



Looking at the heavens with both eyes is easy when you ride in Pierre Schwaar's 8-inch binocular chair. Motors move the chair and telescope.

For me, and for Kevin, Denny, Vance, Ron, and a thousand other telescope makers, the 1991 Riverside Telescope Makers Conference has begun!

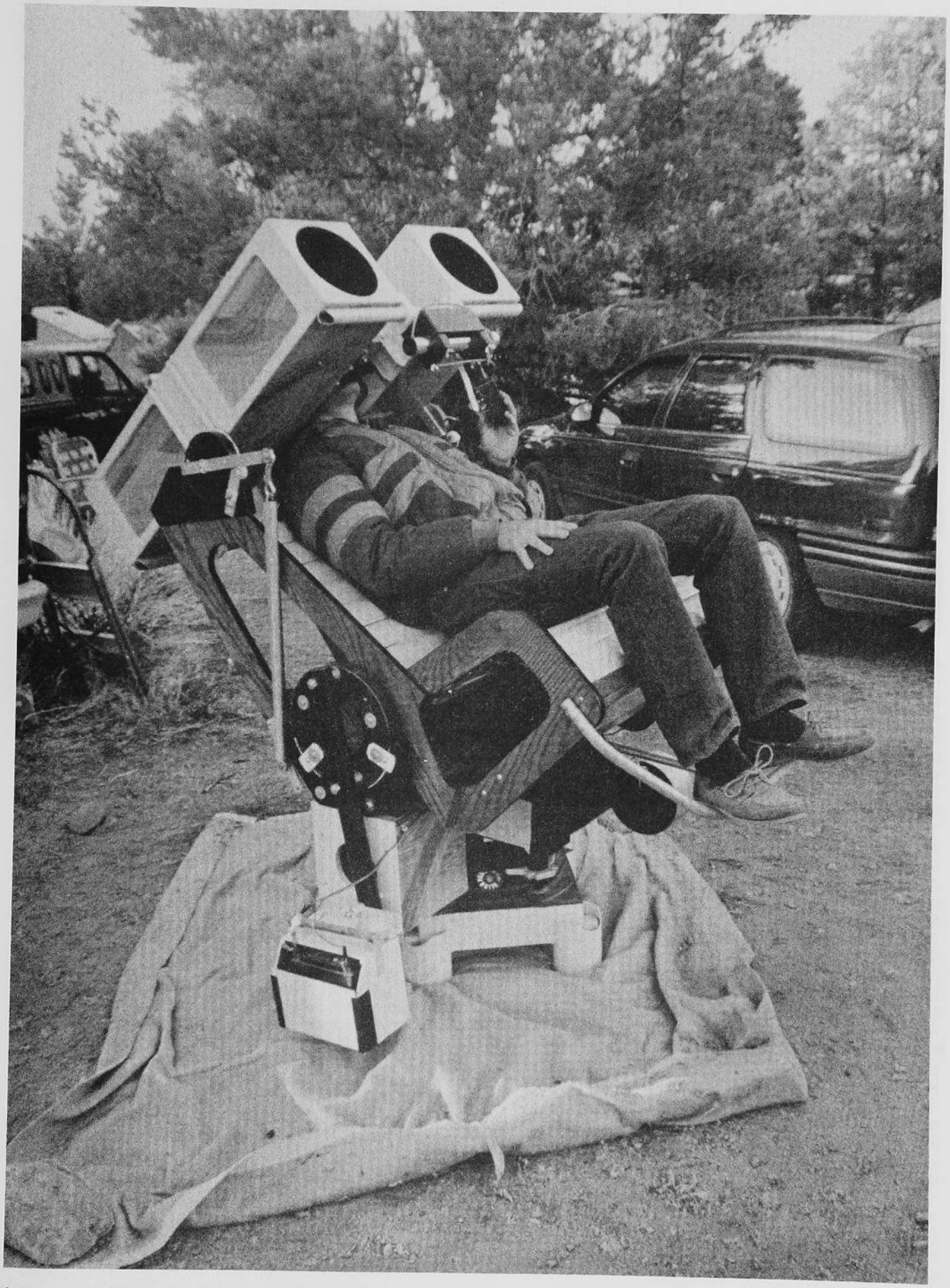
A Quiet Year for Telescopes

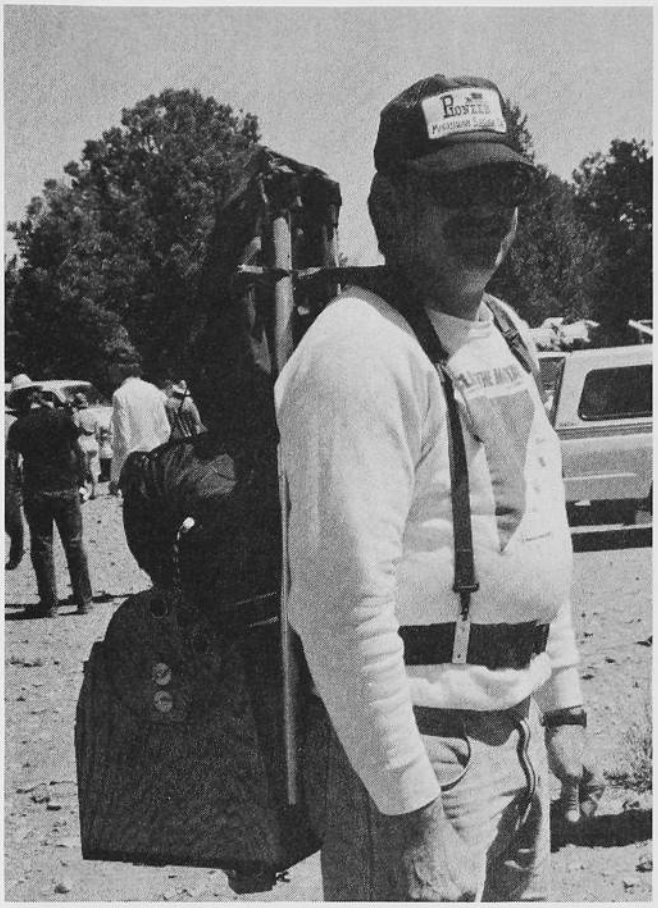
To avoid the horrendously long line up of cars and campers that understandably annoys the people living around Camp Oaks, the conference started Friday morning. Bargain-hungry people were lining up at the commercial booths as soon as they were set up. Some dealers had their hands slapped by organizers for starting to sell their wares a little too early!

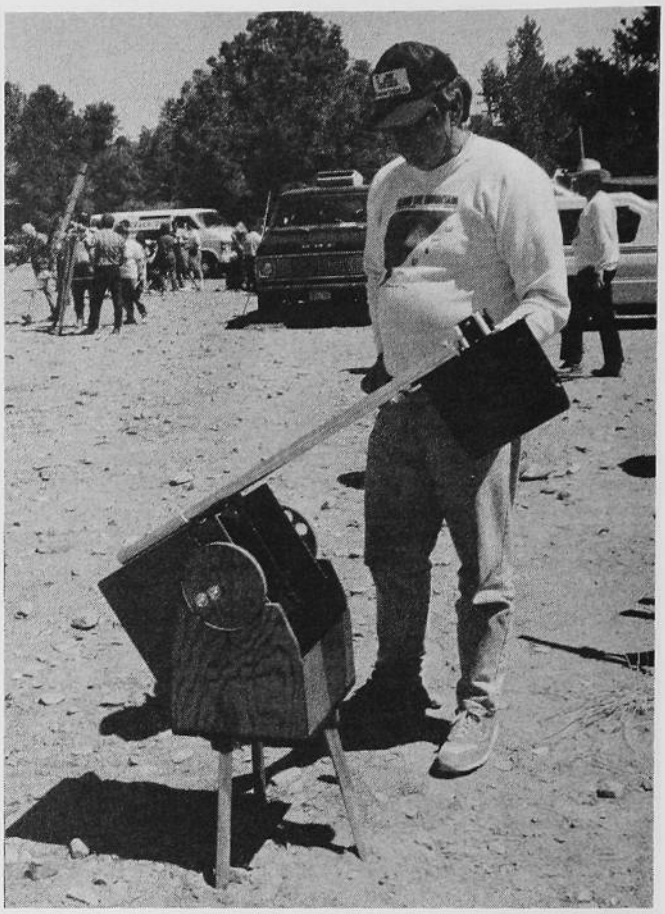
But this year the number of new telescopes on display was down considerably from several years ago. Indeed, by Saturday afternoon the telescope field looked bare. (On the Saturday nights of other years, the field buzzed with voices and long lines led to the interesting telescopes.) This year's Saturday night was almost quiet, and by Sunday morning many people had left. Sunday night the field was nearly deserted.

The most obvious reason for the low level of astronomical activity was the nearly full Moon in the sky that seriously hampered observations of the faint fuzzies that we all know and love. RTMC veterans that I asked said the economic recession forced some people to choose between the July solar eclipse in Mexico and RTMC.

Yet despite the scarcity of tele-







The backpacker's special (above) lets Jim Stevens pack his 10-inch f/4.6 Dobsonian into remote (and dark!) sites. Opposite page, upper left: Artur Guilfoil built his 4-inch f/12 telescope from the ground up over a 13-year period. Upper right: Collimation is no problem with Steve Collett's 12.5-inch Dob. The knobs are easy to reach from the eyepiece. Lower left: Drills serve as drive motors in Wayne Schmidt's binocular chair. Lower right: Brian McFarland, Bill Griffin, and Ray Massey joined forces to build a small-car portable 10-inch Dobsonian.

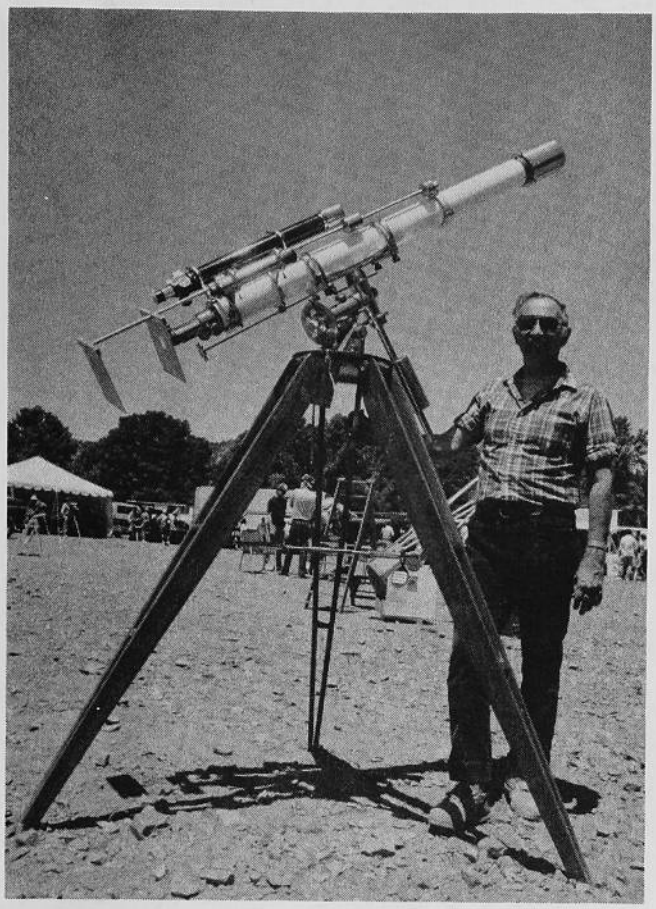
scopes and the relatively low attendance, most people, including myself had a great time. At the core, telescopes are only part of a convention like Riverside. I enjoyed walking around and talking to the people who were there, finding out what they are up to, and listening to the latest gossip.

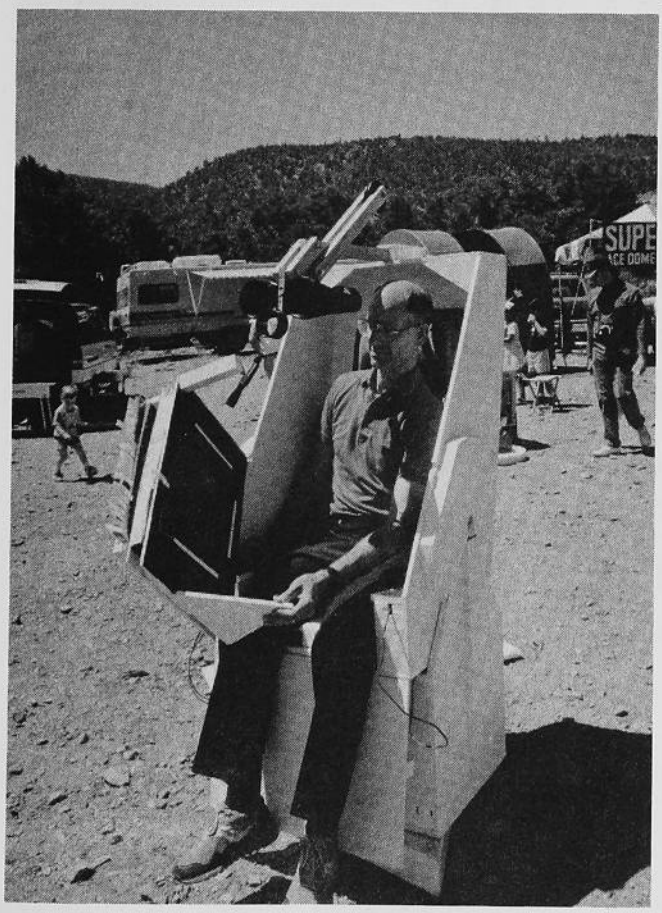
For example, at the Friday night paper session I showed some slides of my coating machine and described my experiences aluminizing mirrors (this will be covered in a future issue of TM). The next day Imelda Joson and Edwin Aguirre of the Philippine Astronomical Society tracked me down and introduced themselves. It turns out that they had also acquired an aluminizing machine in the States and shipped it home to coat mirrors for Philippine TMs. They went to great lengths to get a coating machine because there is no commercial firm in their country that could do the job. Having the coatings done outside the country is a hassle. And I thought we had it bad in Canada!

Norm Sperling of Oakland California and president of Everything in The Universe delivered a talk about how little things have changed in the telescope business. A hundred years ago, customers complained bitterly that they were forced to wait inordinate lengths of time for their telescopes — enough said! Norm also unveiled the book "Dobson on Dobsonians" which he edited. This book stands out on the coffee table because it is not your ordinary paperback book. Instead, it is bound in 1/4-inch plywood or Masonite, your choice, in the Dobson tradition. My copy is bound between oak covers and is sure to become a collector's item.

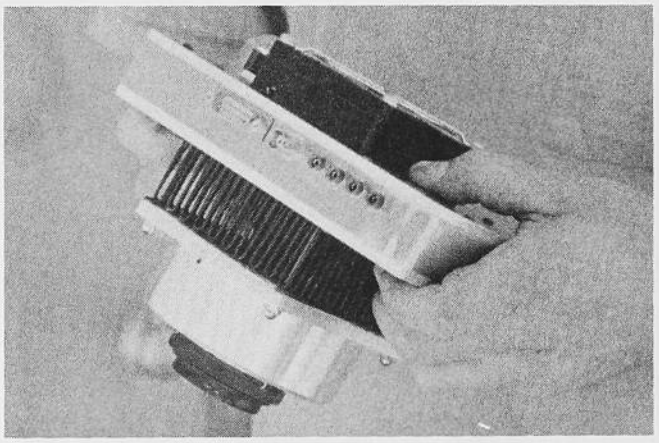
Not all the interesting talks were scheduled. In an informal show-and-tell session, Bill Anderson described a sexy new optical design program written by Ken Moore of Tucson. This program is within an amateur's budget and very powerful. In fact, I think it does all the things of software costing ten times as much. Dean Kettelsen, a professional optician from Tucson, demonstrated the program for a few of us amateur ray benders on a borrowed computer. I was amazed at the quality of the graphics and the friendly user interface. In my opinion, this software is a dream come true for the amateur designer. TM is definitely going to follow up on this, so stay tuned.

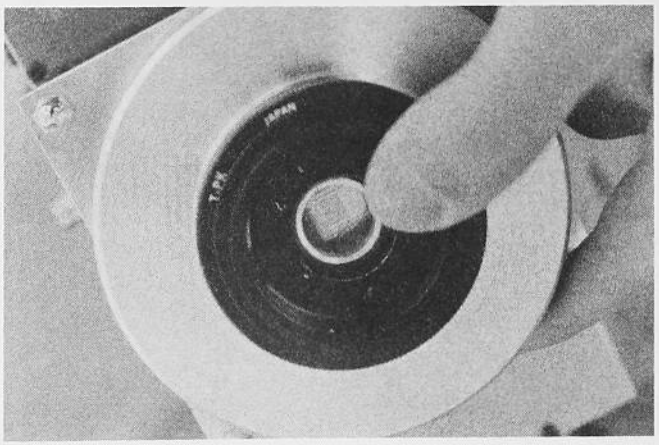
Dean works at the Steward Observatory, currently on one of Roger Angel's 3.5-meter spin-cast mirrors using a high-tech deformable polishing lap. When Dean mentioned that he had a few slides of the polishing operation and equipment and offered to show then to me, I coaxed him into showing the slides at the show-and-tell session. The spin cast Pyrex blanks are polished after being generated with a diamond wheel — without any grinding. All generating marks and pits are removed by polishing alone! Dean says that polishing the 3.5-meter diameter f/1.5 parabola is as easy as polishing a

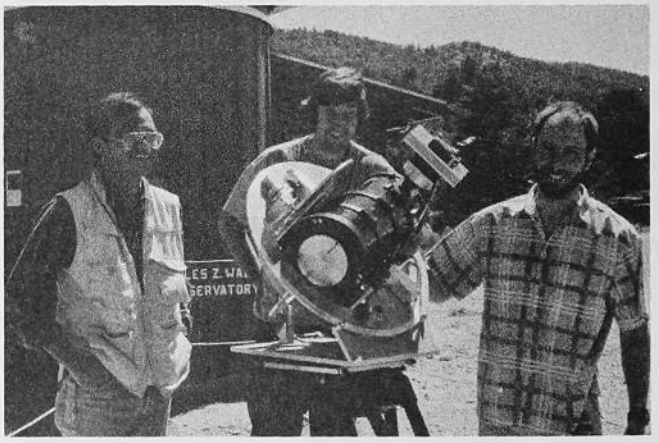




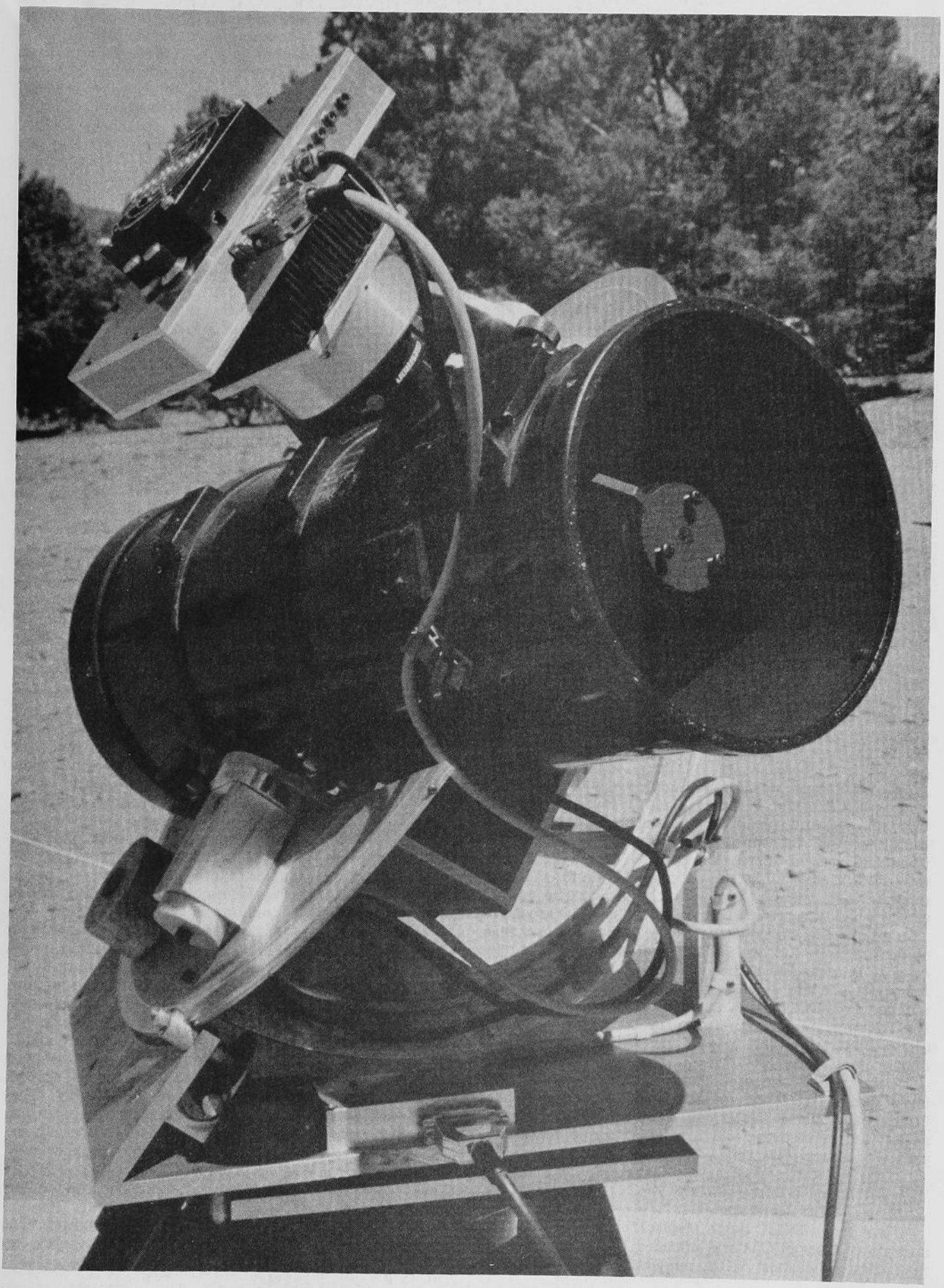
PIXEL PUSHERS







Is amateur astronomy doomed to become a spectator sport — or might CCDs spark new interest and revolutionize observing? A crowd of amateurs watched (top) as Vance Chin, Kevin Medlock, and Ron Story's 8-inch f/3 Newtonian collected celestial images under remote control (opposite). The sensor is a 640x480 chip from Philips with 6.7-micron pixels mounted in a vacuum chamber and cooled to -55°F. This spectacular demonstration of automated observing under a moonlit sky may have been the high point of the 1991 RTMC.



sphere when one is using the computer-controlled stressed-lap technique and a null tester.

Some things at Camp Oaks never change even when they should. The only thing the camp's food had going for it this year was the convenience of eating on-site. For example, one night's dinner consisted of a plate of saturated fat shaped like a chicken leg and thigh. On another memorable occasion, one of the camp chefs was serving up spaghetti with his bare hands! It wasn't long before I abandoned my meal tickets for the hamburger stand. On several occasions though, Alan Dyer and Cathy Odland of ASTRONOMY magazine rescued me from the gastronomic hell and took me out for dinner in town.

Camp food does not have to be so bad. I have fond memories of the food at the Prude Ranch at the 1988 Texas Star Party. Is everything really better in Texas?

Well, earlier I confessed that I have a weakness for glass. Roaming 'round and 'round the swap tables Saturday morning I noticed Dean Kettelsen sitting with what looked to be a large piece of optical glass. An 11.75-inch-diameter piece of F15 flint glass with the melt data sheet. Dean, representing the Tucson Astronomical Association, was willing to let this little gem go for $100. I eyed it for a long time. It would be just right for an 11-inch refractor like Jeff Schroeder's famous Volvo-mounted scope (TM#30) at one-fourth the price of a piece of flint glass from the factory!

I hemmed and hawed. Seductive visions of ultra-high-contrast planetary images and clean Airy disks unadulterated by multiple reflections and central obstructions filled my mind. Then I made the ultimate mistake — I touched the blank. I was gripped by a growing madness!

In an effort to save myself I tried to concentrate on the gobs of residual color to be expected with such huge refractors — but it was too late. I recalled Roland Christen's article on the Trispace corrector that can turn an ordinary doublet into a near apochromat.

In the end I succumbed to the fever that is telescope making and bought the blank. After all, why should Jeff remain the only amateur with an 11-inch refractor?

The Latest in Home-Grown CCD Cameras

At last year's RTMC Kevin Medlock and Vance Chin of Oakland unveiled their first-generation CCD camera based on a huge 640x480 Philips video CCD chip with 6.7-micron pixels (see TM#41, page 34). It was a daunting unit with cables sticking out in all directions and pipes and tubes for the water-cooled Peltier coolers that chilled the CCD chip to reduce thermal noise. Teaming up with Ron Story of Portland, Oregon, Kevin and Vance completely redesigned the previous system and created a fully computerized, remotely controlled, imaging telescope.

The 8-inch f/3 Newtonian's compact split ring mount and the camera hardware were designed and built by Kevin . Vance extensively modified the CCD chip's electronics so it would integrate and make astronomical imaging practical while Ron's expertise was directed at the computer control system and software that points the telescope and keeps it locked on the target.

A CCD camera coupled to a computer-driven telescope is a marriage made in heaven. I have watched amateur astronomers struggle for half an hour or more to center an object on a tiny CCD chip that requires only seconds to record. With this automated system, stars whizz by on the monitor (with the camera in video mode) as the computer slews the telescope slightly past the desired object then back again to take out any backlash in the drive system.

The new camera features a three-stage thermo-electric cooler and a forced-air-cooled, pin-fin heat sink to chill the CCD chip to -55 degrees F. Calibrated thermistors on both the hot and cold sides of the Peltier coolers monitor the system's efficiency.

The control center for the telescope consisted of several computers (one for imaging the other for pointing). The computers were linked to the 100-foot distant telescope and camera by a fiber optic cable. As Ron directed the telescope to objects and Vance operated the camera, the control center was the place to be on Saturday night.

Amazingly enough, the team had just gotten the system up and running just in time for its debut at the conference. Alas, it had yet to be perfected. Whenever a glitch would develop Kevin re-oriented the telescope manually. Despite such problems, for me this total imaging system was the technical highlight of the conference.

Whatever Happened to TOMA?

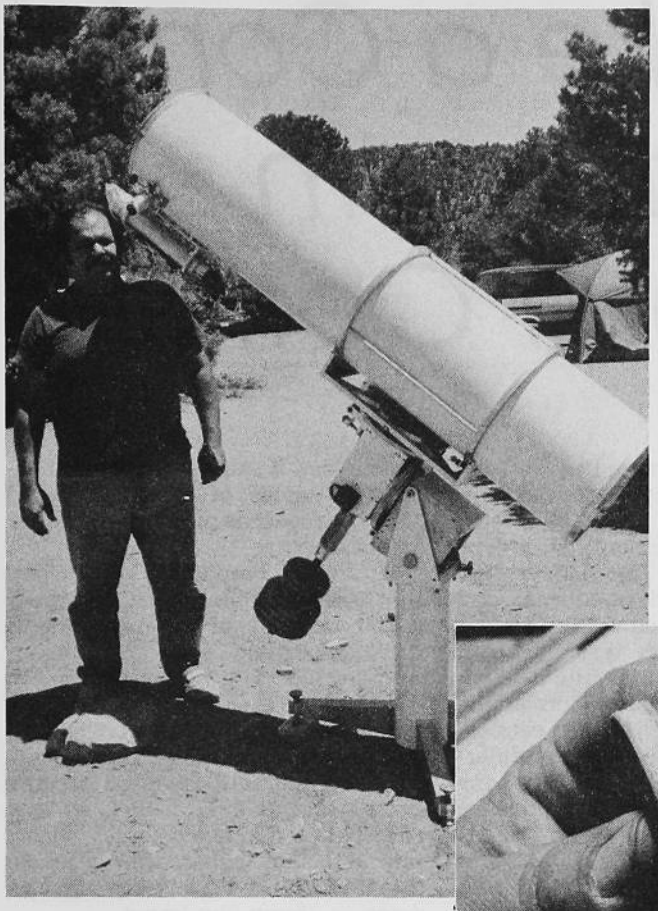
Last year a fledgling group called the Telescope Optics Manufacturers Association (TOMA) met at the Riverside conference. It was an unprecedented event: representatives from most major telescope manufacturers and three magazines were present. After much discussion of optical quality and advertising practices, committees were formed to address a variety of issues (see TM#41, page 40). But a year later little has materialized. It appears that TOMA is dead.

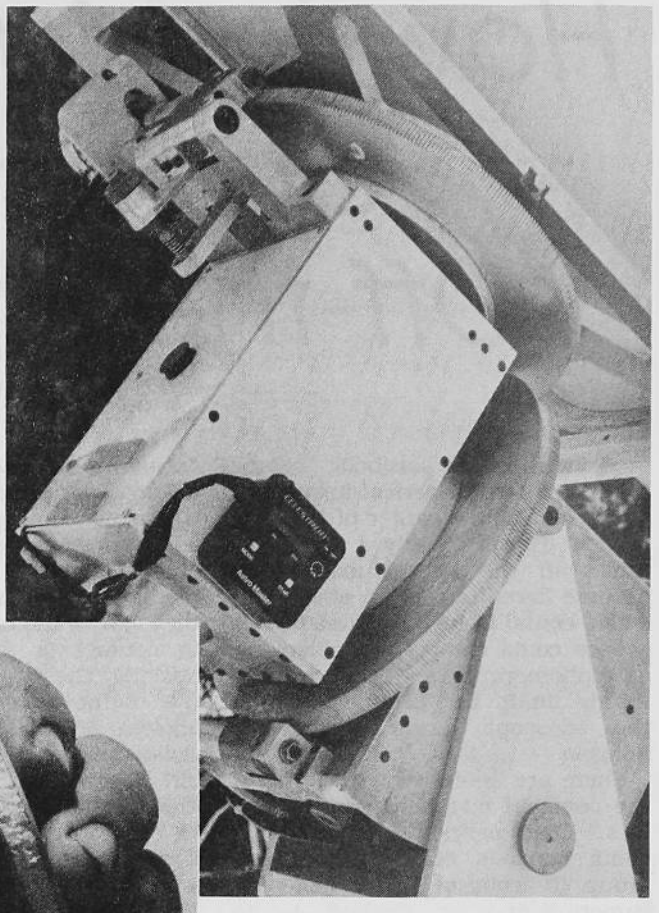
Not surprisingly the most manufacturers, the people who were supposed to make TOMA work, are too busy making telescopes to give TOMA the attention that it needed to succeed. Some of the manufacturers also seemed to loose interest in the organization. While there was no scheduled meeting at this years RTMC, Bob Goff, an independent optician who was present at last year's TOMA meeting, called an impromptu and informal gathering, open to anyone interested, to discuss TOMA and the problems it was supposed to address.

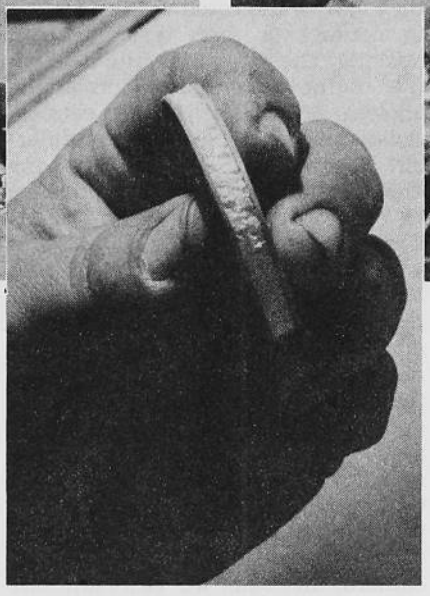
Present were a few opticians and two dozen amateur astronomers. What I found most interesting from the round-table discussions was that people expect a lot from the magazines. Many people feel the magazines should police the manufacturers, doing everything from monitoring the optical quality telescopes to controlling their advertising practices. While the magazines have a role to play in protecting the consumer from poor products and fraudulent advertising, the reality is that magazine editing is a full time job which leaves editors little or no time to monitor the industry.

Everyone did agree however that some type of organization was needed to address the concerns of optical quality and advertising practices. Personally, I would like to see a consumer organization founded and run by amateur astronomers hell-bent on looking after the interests of the amateur community. I feel that in order for such an organization to have any teeth it must have many member amateur astronomers to support it. Dues paid by the members would enable the organization to purchase commercial telescopes and review them thoroughly. The reviews could be published in a newsletter that did not carry advertising or rely on advertising revenue for its existence.

Send your suggestions and/or letters of support to: Richard Combs, 4443 Second Street, Pleasanton, CA 94566. Combs' phone number is (415) 846-1906.







Moe Ashley brought his 12.5-inch Newtonian mounted on a solid mounting made of aluminum plate. Part of the reason for the telescope's solidness is that the tube weighs a total of eleven pounds. It is made from 2-pound styrene foam and 0.040-inch fiberglas sheet cemented with epoxy. The photo at left shows a cross-section that was cut for the

The long overdue hell-raising about optical quality that occurred in the magazines over the last several years helped to clean up misleading and sometimes fraudulent advertising. Flipping through some of the latest issues of the magazines makes plain that some advertisers have returned to the advertising practices of the past. This happen because there are still no industry-approved standards for advertising claims. If enough bad optics get out, word-of-mouth eventually kills the offending company, but by that time many people will be stuck with bad products.

Richard Berry and I have gone to great lengths to make amateur astronomers aware of poor optical quality and misleading advertising among some manufacturers. Telescope Making magazine has conducted several testing sessions and has published many articles addressing this topic.

Personally, I wonder how concerned TMs are about optical quality and advertising practices. The readers of Telescope Making magazine included virtually all of the technically knowledgeable amateur astronomers, and this groups can have a significant influence on where the hobby, both commercial and amateur, is heading.

I am interested in hearing from you: Do you think there is a problem with optical quality? If so what are you willing to do about it? The response, or lack there of, will set the tone for how we handle the optical quality issue in the future. Send letters to my address below. If we get a good response, we'll publish a selection in a future issue of TM.

Homeward Bound

This year I had a bit of time to kill before my flight home so I accepted Rick Schafer's invitation and visited him at his home in Pasadena. Rick is famous at the RTMC for his fabulous "junque". Most years he shows up with an interesting gizmo that is begging to become part of a telescope.

Rick proudly showed me around his garage, a small building that is loaded to the gills with gadgets of all kinds. All potential telescope parts, of course. Rick even offered me a few choice goodies but I had to turn him down since there was only so much I could carry on the plane. Indeed, the final challenge of the weekend was to stuff all the things I did pick up into my luggage and figure out how I was going to get that beautiful hunk of glass home safely.

Although the level of activity was low this year, I think every one went away happy. I'm already looking forward to next year's RTMC.

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Gloucester, Ontario
Canada K1J 9L9

How to Make a Coma Corrector with Off-the-shelf Optics

A well-made parabolic mirror will form a perfect image of a star at the center of the field of view. However, only a short distance off the optical axis, stars become flared due to an aberration called coma. In fast Newtonian telescopes coma creates a problem for astrophotographers because the flaring limits the field over which the telescope forms sharp star images.

There are several ways to correct the coma in fast Newtonian reflectors. One method of correcting coma consists of placing a lens group in front of the eyepiece or camera. Another method is to design an eyepiece that includes coma compensation. Because commercially available correctors and compensated eyepeices are expensive, I thought it would be interesting to see what the TM could put together from inexpensive off-the-shelf lenses mounted in a homemade cell.

Because I am a professional lens designer, I have access to the specifications of stock lens components from several suppliers. Stock lenses are usually made of a standard glass such as BK-7 and are either plano-convex, bi-convex, plano-concave, or bi-concave. Lacking is the wide range of glass types and lens shapes that I would normally prefer for optimizing a design. Nevertheless, it is possible to fabricate coma correctors from stock lenses.

While the resulting correctors may not be as highly optimized as commercially available systems, they can deliver acceptable performance at a far lower cost than the commercial units. None of the designs discussed below has any magnification, and they cause very little shift in the image position. The back focus distance is more than adequate to accommodate a camera body.

The first corrector, specified in the accompanying tables as Design #1, is a two-element Ross-type coma corrector. The lenses are plano-concave and bi-convex, and they can be mounted with the edges in contact or with a small edge spacing. The design is quite insensitive to the exact separation of the lenses. According to the catalog, these two lenses have slightly different diameters, as the drawing shows, and so the cell would have to accommodate this slight difference.

A second corrector, Design #2, offers better performance but requires three lenses to achieve it. I arrived at this design because the negative lens in Design #1 should really have a meniscus shape for optimum performance. Although stock lens houses carry a few meniscus lenses, the combinations that produce good image quality produce too short a back focus distance for photography with a 35mm camera. Instead, we can simulate the optimum meniscus lens fairly closely by combining or cementing a plano-convex and a plano-concave lens together. Read Bob Cox's instructions for cementing lenses in *TM#28*, but bear in mind that cementing will be difficult because the diameters of the lenses are different. The cost of the three lenses, purchased uncoated, is about $74.

When evaluated with a 10-inch aperture f/4.5 parabolic mirror, Design #2 comes close to meeting the standard photographic criterion of a 25-micron spot size over the whole 35mm film format. It is important in such evaluations to consider only the rays that actually get through to the focal plane because there is some vignetting in the outer parts of the field because of the diameters of the lenses. Vignetting can be minimized by mounting the lenses in a narrow-lipped cell to expose as much of the lens as possible.

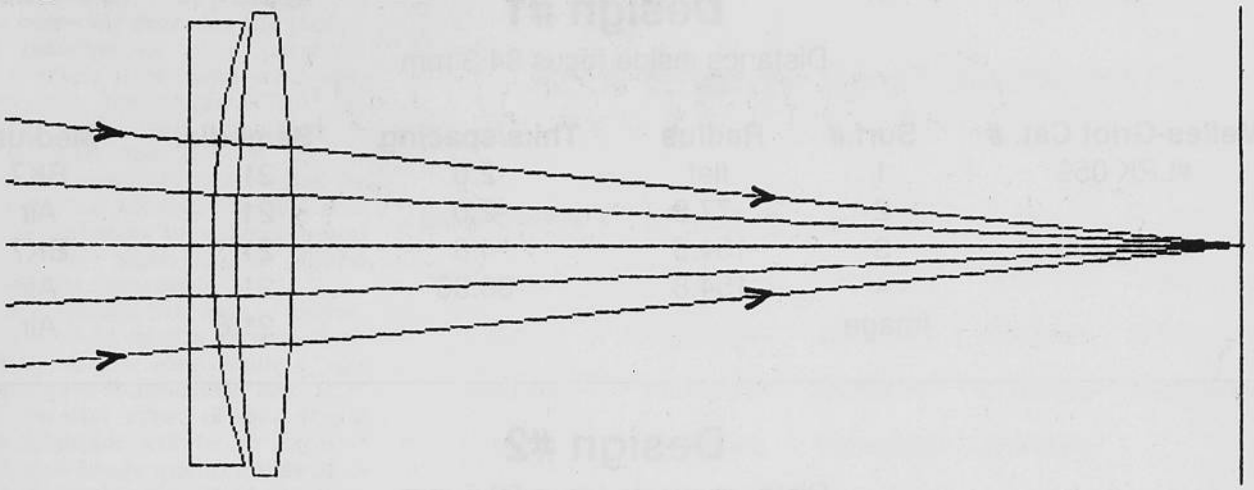
The table compares the spot size that includes 85% of the light from a star for each of these designs to the comparable spot size for an uncorrected f/4.5 paraboloid. In each case, the comparison is over a 35mm format, and takes vignetting into account. Although the designs are not diffraction-limited in the center of the field (which in any case is not necessary for photography at prime focus), they produce dramatically better star images across a 35mm film frame.

Essentially the same results would be obtained with other f/4.5 parabolas of different sizes. There is probably too little improvement in performance between Design #1 and Design #2 to justify the cost and complexity of the third lens element.

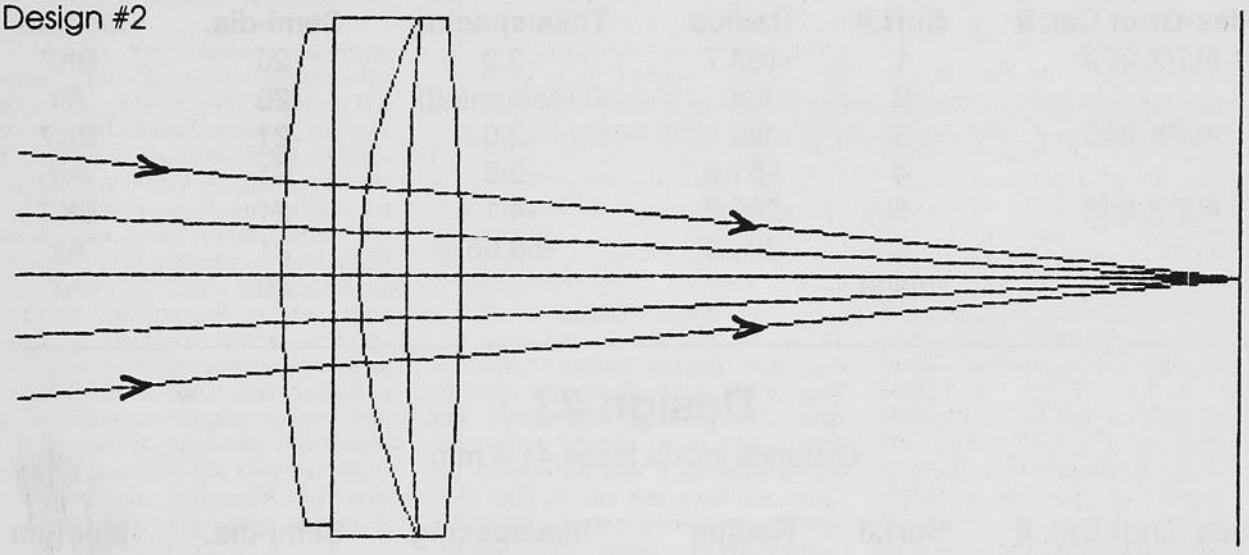
Design #3 is a much smaller coma corrector which is intended for visual use only. Note that the back focal distance is insufficient for photography with normal cameras. Over a slightly curved field 20mm in diameter, the spot sizes at best focus are about half those produced by Design #2. This was possible because a suitable meniscus lens was available for the leading lens. It is shown at the same scale as Designs #1 & #2. The pair of lenses for this design costs about $40. Because of their small size, getting a magnesium fluoride coating would cost about $14 for each lens.

The steep light cone of an f/4.5 primary mirror brings out enough spherical aberration and color in standard eyepieces, and there is hardly any point in trying to improve the axial performance of Design #3. Indeed, it turns out that this design happens to have axial color of the

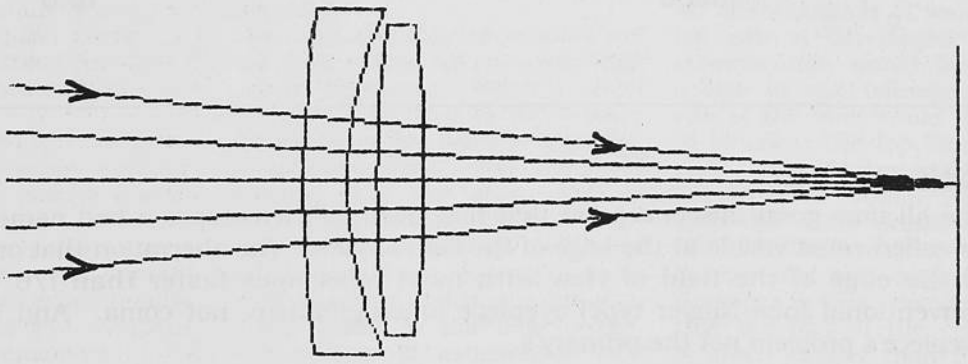
Design #1



Design #2



Design #3



Design #1

Distance inside focus 84.3 mm

Melles-Griot Cat. #	Surf.#	Radius	Thks/spacing	Semi-dia.	Medium
#LPK 059	1	flat	-2.0	21	BK7
	2	-77.8	-2.0	21	Air
#LDX 203	3	-154.8	-4.8	21	BK7
	4	154.8	-80.36	21	Air
	Image			21.6	Air

Design #2

Distance inside focus 69.5 mm

Melles-Griot Cat. #	Surf.#	Radius	Thks/spacing	Semi-dia.	Medium
#LPX 269	1	-103.7	-3.9	20	BK7
	2	flat	0 (cemented)	20	Air
#LPK 045	3	flat	-2.0	21	BK7
	4	-51.9	-3.5	21	Air
#LDX 203	5	-206.8	-4.1	21	BK7
	6	206.8	-58.68	21	Air
	Image			20	Air

Design #3

Distance inside focus 41.4 mm

Melles-Griot Cat. #	Surf.#	Radius	Thks/spacing	Semi-dia.	Medium
#LMN 001	1	-90.0	-3.0	12.5	BK7
	2	-32.6	-2.0	12.5	Air
#LDX 167	3	-103.2	-3.2	11.2	BK7
	4	103.2	-36.24	11.2	Air
	Image			10.0	Air

Editor's note:

The all time great misconception that has given fast telescopes a bad name is the so-called coma visible at the edge of the field of view. The aberration that one sees at the edge of the field of view with most telescopes faster than f/6 with a conventional (non-Nagler type) eyepiece is astigmatism, not coma. And it's the eyepiece's problem not the primary's.

type needed to improve the color correction of most eyepieces.

Unfortunately, the Design #3 coma corrector degrades the perfect axial performance of a parabolic mirror when it is used with eyepieces like the Nagler. The 11-micron axial spot diameter is almost twice the size of the 6-micron diameter of the Airy disk for the 10-inch f/4.5 reflector, and this blur corresponds to a 2-arcsecond image blur when it is viewed through the telescope.

At first glance this loss of performance sounds terrible, but remember that at low magnification you cannot see a 2-arcsecond blur anyway. The net effect of this visual coma corrector will be to improve the overall image quality in the field for aesthetically pleasing low-power views. For high-power observing, of course, you should remove this coma corrector.

In using any coma corrector, whether this one or a commercially made one, you cannot improve the edge-of-field performance of an eyepiece which suffers from severe astigmatism. Only Nagler-type eyepieces, which are corrected for astigmatism, will profit from the addition of a visual coma corrector.

The cost of the two uncoated lenses in Design #3 is $54 plus shipping. Because there are no ghost images that even come close to being in focus, anti-reflection coatings are not required, but you want to consider having the lenses coated to improve the overall transmission of light. The additional cost for a magnesium fluoride coating is $25 per lens.

All the elements in these designs are available from the Melles-Griot optical company. This firm offers the widest range of stock lens radii and diameters that I know. Melles-Griot can be reached by phone at 1-800-835-2626 in the States, in Canada at 1-800-267-3497, in Europe at (08360) 33041 (the Netherlands), and in Asia at (03) 407-3614 (Japan).

In summary, although the three designs I describe here are not fully optimized, they can provide a substantial improvement in off-axis image quality in fast Newtonians and they demonstrate that impressively large gains in image quality can be accomplished with inexpensive off-the-shelf components.

David Shafer
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Fairfield, Ct. 06430

85% Energy Spot Diameter

image diameter	f/4.5 parabola	design #1	#2	#3
0.0 mm	0.0 microns	23 microns	19 microns	11 microns
10.0 mm	35 microns	24 microns	20 microns	11 microns
20.0 mm	70 microns	26 microns	21 microns	13 microns
30.0 mm	105 microns	28 microns	23 microns	
40.0 mm	140 microns	40 microns	32 microns	

Note that designs #1 and #2 are evaluated on a flat image surface, but #3 is at best visual focus for each field point. It is very nearly flat.

Editor's Note

"Coma" ranks among the top all-time misconceptions that give fast Newtonian telescopes a bad reputation. While it is true that the images in fast Newtonians are often soft at the edges of the field, the aberration responsible is astigmatism, not coma. Furthermore, this aberration occurs in the eyepiece and not in the primary mirror. Standard eyepiece designs all suffer from astigmatism at the edge of the field; only in Nagler-type eyepieces is this astigmatism corrected.

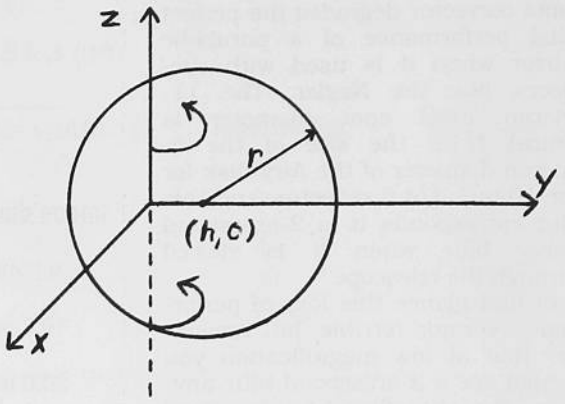
You can test this for yourself the next time you're out observing with a fast Newtonian. Place a non-Nagler-type eyepiece in the focuser and examine the stars at the edge of the field. Those edge stars will probably look like short arcs or lines concentric with the field stop. If you rack back through focus and watch those lines, they will shrink down to a blur and then expand to a line radial to the field center. That pattern is astigmatism and not coma. Coma flares stars out into comet-shaped blurs whereas astigmatism stretches stars out into lines.

An excellent illustration of this is found in *Telescope Optics: Evaluation and Design* (Willmann-Bell, 1988), a book that I believe should be in every TM's library. The top illustration on page 186 compares the performance of a 13mm Erfle and a 200mm f/6 Newtonian as stand-alone optical systems and also working in combination. Astigmatism from the eyepiece clearly dominates the star images.

The triangular shape of the spot diagram may seem confusing at first, but you will note that densest concentration of spot is on the left side of the largest blur. This concentration would be visible as a line in the telescope, and the rest of the blur would be too faint to be seen. The top illustration on page 188 illustrates the performance of a 13mm Nagler used with the same primary. Here we see that the eyepiece outperforms the primary and consequently the primary's coma dominates. Note that the size of the comatic blur is much smaller than that created by the Erfle's astigmatism.

— Peter Ceravolo

A Simple Procedure for Producing a Yolo Telescope



It is common knowledge that no optical system will focus the image of a star to a perfect point. Instead, the stellar image consists of a diffraction pattern with a bright central disk (the Airy disk) surrounded by diffraction rings, each successive ring dimmer than the preceding one. The image of an object other than a star will consist of myriad overlapping diffraction patterns.

What determines how "contrasty" an image will appear is the way in which the optical system distributes the light in the diffraction pattern which it forms. As an example, take two planetary features which differ by only a small amount in surface brightness and have an angular separation such that they should be resolved by the optical system. According to Lord Rayleigh, this means that the first diffraction ring of one feature overlaps the Airy disk of the other. Now the first ring of the brighter feature is contributing to the brightness of the Airy disk of the second feature. If the two features differ only slightly in surface brightness, this blending may render them indiscernible.

Why are the Airy disk and first ring so important? Together, they contain most of the light in the diffraction pattern, and it is the difference in their brightness which ultimately determines how well a system resolves low-contrast image features. For maximum contrast, the optical system must focus the largest possible fraction of the light in the diffraction pattern into the central Airy disk and as little as possible into the surrounding rings. This will minimize the contribution of the first ring of one diffraction pattern to the Airy disk of one adjacent to it.

In an unobstructed optical system, the Airy disk contains 84% of the light in the diffraction pattern. The first ring contains another 7%, and all of the remaining rings contain the remaining 9%, which is so spread out that its contribution to the contrast equation is negligible. This distribution gives a ratio of light in the Airy disk to light in the first ring of about 12:1. This is the highest ratio attainable with a uniformly illuminate pupil.

When an obstruction is placed in the light path, the light in the diffraction pattern is redistributed. For an obstruction with a diameter of .25D (where D equals the diameter of primary mirror), the ratio of light in the Airy disk to light in the first ring drops to 4.06:1. This redistribution of light caused by the central obstruction reduces a system's ability to resolve low-contrast image detail.

The quest for the solution to this problem gave rise to Tilted Component Telescope designs. The thread that unifies all TCT designs is the elimination of the central obstruction by tilting the primary mirror to allow the remaining optical elements to be located outside of the light path. The Yolo optical system is a two-element TCT in which the tilt of the secondary mirror is adjusted to cancel the coma of the primary. The secondary must be given a toric surface figure to eliminate astigmatism; spherical aberration is corrected by applying a hyperboloidal figure to the primary mirror.

The distinguishing element in the Yolo design is the toric secondary mirror. You can picture a toric surface as a small patch on the equator of a large sphere which is compressed at its poles. It should be apparent that this figure is not axially symmetric. The "trick" to making the Yolo, then, is generating this figure on the secondary mirror.

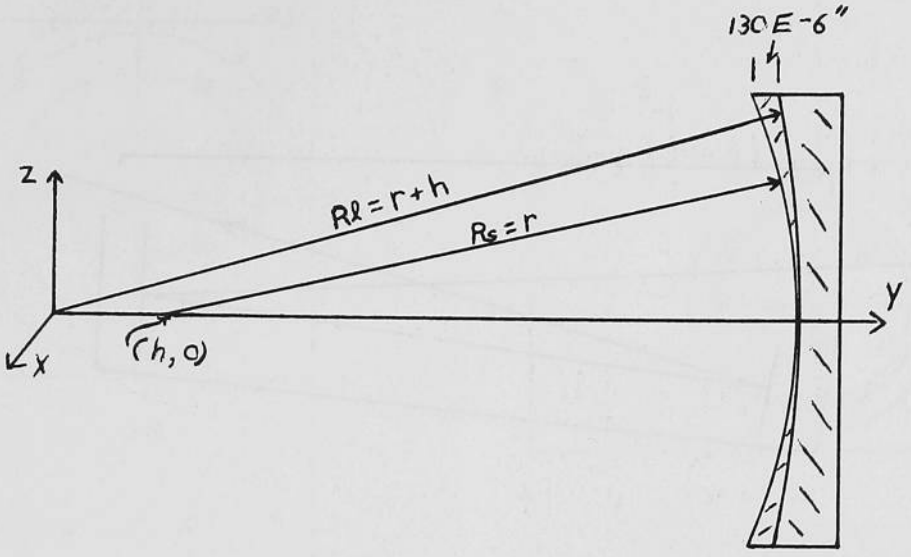
Working Up the Design

The first step is to produce an optical design using third order theory. If you are no whiz at Seidel theory, see "Designing a Yolo Telescope" by Jose Sasian in *TM#37*. Study these formulae and work through the design example that Sasian provides. If you get the same answers as he did, then you are ready to proceed. Even if you're pretty sure of what you're doing, I'd recommend that you have a look at that article.

The best way to generate the design is to choose a primary diameter and effective focal length. You will also need to decide where you want to place the focal plane with respect to the primary mirror. You should take into account things like the mirror cells, the height of the focuser, focuser travel, etc. Next, experiment with the primary and secondary radii of curvature and the secondary diameter until the system meets your requirements. A computer or programmable calculator will definitely speed this process along but they are not absolutely necessary.

Make a scale drawing of the final design to verify that nothing strange has happened. It is possible to generate a system in which the beam passes through the primary mirror on its way from the secondary to the focal plane. Obviously designs like this should be avoided.

The next step is to grind and polish both mirrors



out to spheres. If you can get the radii accurate to within 6 inches of the desired radius values, this should be fine. You can always measure whatever radii you end up with and use these in the design formulae to see what comes out. If the new design is not too far from what you wanted to begin with, you can leave them where they are.

Figure the hyperboloidal primary using the normal parabolizing stroke. You can calculate the knife edge displacement for the Foucault test in the usual manner, except that the whole expression must be multiplied by the primary K-factor derived from Sasian's design formulae. Because of the long radius of curvature of this mirror, the figure will go in very quickly. To give you some idea, I've found that figuring the primary for a 6-inch f/12 system requires approximately 4 to 6 minutes of actual polishing time.

The Toric Surface

In order to apply a toric figure to the secondary mirror you must develop some feel for how much glass must be removed and where. To generate a spherical toric surface, define a decentered circle in the yz plane by $(y-h)^2 + z^2 = r^2$, where (h,0) are the y and z coordinates of the center of the circle and r is its radius. (This is shown in Figure 1). If this circle revolves about the z axis it will sweep out a spherical toroid. If the y-decenter is made larger then r, then the familiar doughnut shape is obtained. In our case, however, the y-decenter is small compared to r and we obtain a slightly "squashed" sphere.

The part of this toric surface that we are interested in is a small circular patch on the equator. This patch represents the secondary mirror of the Yolo. It faces the origin, and the y-axis runs through its center. From Figure 1, it should be apparent that the mirror has two mutually perpendicular radii of curvature. One radius is equal to r and lies in the yz plane; the second radius is equal to (r+h) and lies in the xy plane.

In all other respects, however, the mirror is spherical. If it is cut at any orientation perpendicular to its surface, the intersection of the cut and the surface will be the arc of a circle. The radius of curvature of this arc will vary with the orientation of the cut. The arc will have a maximum radius if the cut is made in the xy plane and a minimum radius if it is made in the yz plane. This explains the fact that a Ronchi test will give straight bands at any grating orientation. Basically, as the orientation of the grating is changed, it is testing a different radius of curvature on the mirror, hence the variation in band width and separation.

Let us now consider how the glass should be removed in proceeding from a spherical to a toric surface. In what follows, numbers from a 6-inch f/12 design will be used. The secondary diameter is 4 inches and it has a short radius, Rs (in the yz plane), of 231 inches. The long radius, Rl (in the xy plane), is 234.5 inches. If you start with a spherical mirror of radius 231 inches and cut it perpendicular to its optical axis in the xy plane as shown in Figure 2, you will find that the radius of curvature in this plane is too short.

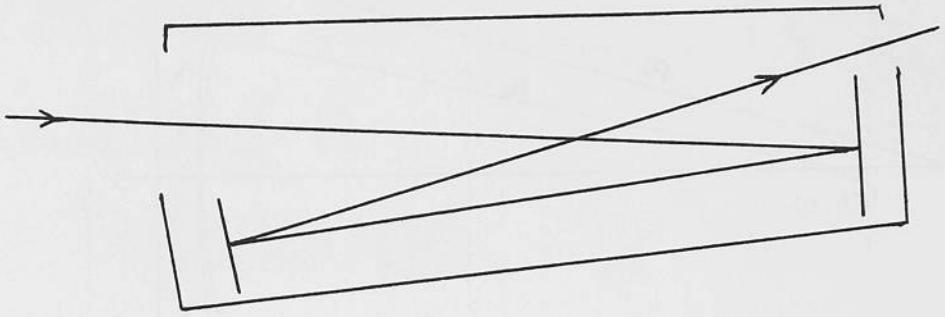
A certain amount of glass will have to be removed in order to increase the radius to 234.5 inches. The amount can be determined if a second arc corresponding to the proper radius is drawn with its center tangent to the center of the original spherical mirror. From the yz-plane equations of these two circular arcs, it will be found that the thickness of the glass to be removed increases with the square of z.

The maximum discrepancy between the current arc and desired arc is therefore found at the edge of the mirror. In this extreme case (in which the arcs are tangent at the center), most of the glass would have to be removed from the upper and lower edge of the mirror. In the other extreme (in which the arcs intersect at the edges), the polishing action would have to be concentrated at the center of the mirror.

For a mirror of the previously mentioned dimensions, the maximum thickness to be removed in either extreme case is approximately 1.3×10^{-4} inches. For comparison, an 8-inch f/4 parabola (R = 64 inches) and a circle of the same radius have a maximum separation of 9.7×10^{-5} inches at their edges if their centers are tangent. We can reduce the amount of labor involved, however, if we avoid the extremes and use a technique which is a compromise between the two.

Figuring the Secondary Mirror

The first step is to define the Long Radius Meridian (LRM) of the mirror and the polishing lap. With a



straight edge and permanent marker or wax pencil, draw a line bisecting the back of the mirror blank. Extend the line up each side of the blank to the chamfer. Do the same for the polishing tool.

Starting with the mirror below, align the LRM reference lines of mirror and tool so that they are parallel and begin making center-over-center strokes along the direction parallel to the LRM. Do not walk around your work stand. Every 15 to 20 strokes, rotate the tool 180 degrees or step 180 degrees around to the opposite side of the work stand. You should alternate between these two; that is, make 15 strokes, turn the tool 180 degrees, make 15 strokes, step around 180 degrees, etc. The stroke amplitude should vary between $^1/_2$D and $^3/_4$D with a side-to-side variation of about $^1/_4$D. This may seem extreme, but remember that most of the glass to be removed when working in this position is at the outer edge of the mirror.

After 15 to 20 minutes, switch the tool and mirror positions. The LRM reference lines must remain parallel, but now you make your polishing strokes in the direction perpendicular to the LRM. Glass will now be removed from the center of the mirror. The stroke amplitude should be the same as before. I recommend that you cold press the mirror and lap between polishing spells.

The effect of this technique, with the mirror below, is to lengthen the radius of curvature along the LRM. When the mirror is on top, the radius is shortened perpendicular to the LRM. This is the labor-saving compromise that I alluded to earlier. One advantage of using this technique is that the mirror surface errors caused by the unidirectional strokes with the mirror in one position tend to be cancelled out when the mirror is in the other position.

Testing the Toroid

As the mirror progresses toward its final figure, it becomes increasingly astigmatic. However, because the astigmatism polished into the secondary is equal but opposite in sign to that induced by tilting the primary, the two cancel.

If an astigmatic optic is tested with a point source near its center of curvature, it will be found to have two foci. If a screen is mounted next to the source to catch the return image, the point source will be focused to a line at each separate focus. Furthermore, these two line foci will be perpendicular to one another. In the case of the toric Yolo secondary mirror, one focus will correspond to Rs and the other to Rl. This fact forms the basis of a very simple test for determining Rs and Rl.

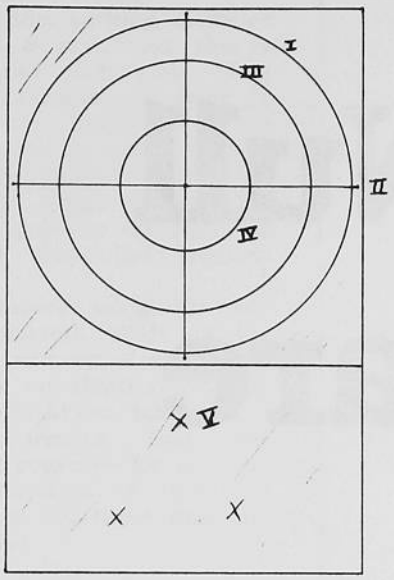
If you stand the mirror on edge for testing with the LRM vertical and place the point source and screen at Rs, the image of the source will be focused to a vertical line. If the point source is replaced by a vertical slit, it too will be focused to a vertical line. Similarly, a horizontal slit placed at Rl will be focused to a horizontal line. All that is required to perform this test efficiently is a slit source shaped like a plus sign.

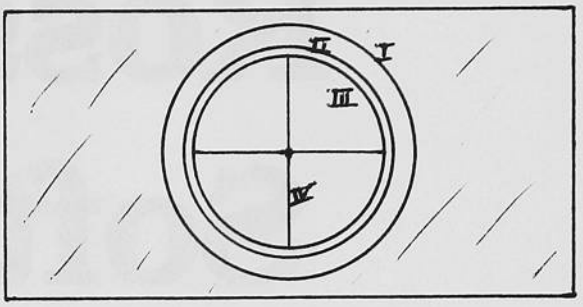
A simple technique for producing a plus-sign slit source is to paint the smooth side of a piece of ground glass with several coats of flat black paint. The plus sign can then be scratched in with a straight edge and Exacto knife. Examine the scratches under a magnifier to make sure they are smooth, then try them out on the mirror. You should experiment with different scratch widths (by angling the knife blade) to determine the width that works best for you. Also, it is best to scratch only the paint and not the glass. Instead of catching the return image on a screen, I use a long focal length eyepiece. To ensure that the focal plane of the eyepiece is even with the slit source, look through the field end and focus the eyepiece on an object located in the same plane as the plus-sign slit.

To use the plus-sign tester, locate the position along the optical axis where the vertical slit comes into focus in the eyepiece. The distance from the source to the mirror vertex is Rs (if LRM is vertical). Slide the tester back until the horizontal slit comes into focus and add the distance moved to Rs to get Rl. If you tape a few sheets of paper to your test bench under your tester, you can make marks and measure their separation directly off the paper.

This test should be used in conjunction with the Foucault knife edge test and the Ronchi test. Remember that the Ronchi test should give straight bands for any grating orientation. The knife edge test for this surface will give two distinct nulls. One focus will null with the knife vertical and the other will null with the knife horizontal. This test is usually a good way to check any suspicions about the figure you may have if the Ronchi test shows bands that are not straight.

As the difference in radii (Rl-Rs) approaches the





desired value, decrease the stroke amplitude. Normal $^1/_3$ "W" strokes should be used with frequent cold pressing to make the surface appear as spherical as possible through the Ronchi test. The better the mirror looks through the Ronchi grating, the more accurate the plus-test becomes.

Collimation

Collimating the Yolo is a snap if it is set up properly. Building the tube assembly is relatively straightforward (see Figure 3). Before you get out the saw and start cutting wood, you should make a full scale layout on one piece of the wood. Draw the box in around the optical layout and use this as the pattern for cutting. Cut the two side pieces together to ensure that they are identical. The rest of the box construction is pretty much up to you.

Before you mount the mirrors in the finished box, place a small dot in the center of each mirror for collimation purposes. The dots should be about $^1/_{32}$ of an inch in diameter. This makes them just large enough to be seen but not large enough to have any effect on image quality.

Next, stretch a crosshair across the entrance aperture of the box. Thin wires serve well for the crosshair. Because you will need the crosshair whenever you collimate, tap small nails into the wood as shown in Figure 4a to leave as permanent posts to wrap your crosshair wires around.

To collimate the primary, sight down the box entrance and center the dot on the primary mirror in the cross hair. Locate the reflection of the secondary in the primary and locate its dot. While you hold the dot on the primary centered in the cross hair, ask someone to adjust the primary mirror collimation screws until the spot on the secondary coincides with the spot on the primary. When you have completed this step, both spots should both be centered in the crosshair.

The procedure for collimating the secondary is similar, except that now you must sight down the focuser tube. To center your eye over the focuser tube, make a $^1/_8$-inch diameter hole in the bottom of a film canister and mount that in your focuser. Look down your focuser at the secondary and have someone adjust the secondary mirror collimation screws until the two dots coincide again, as shown in see Figure 4b.

After collimating the first time, star test the telescope to make sure there is no astigmatism in the image. Out-of-focus star images should be perfectly round. If you see astigmatism, adjust the tilt of the secondary to eliminate it, and reposition the focuser to recenter the dots. If you see coma in your star images, you may need to adjust the mirror separation. The focuser should not be mounted permanently until these fine adjustments are made.

The easiest way to get the mirror separation and tilts right the first time is to measure the finished radii very accurately and optimize the system around these values using an ray-tracing program. I realize, of course, that not everyone has access to such a program, but anyone who gets this far definitely deserves a break. When you send your mirrors out for coating, send me your final values and I will be glad to optimize your Yolo and provide a set of spot diagrams documenting the theoretical performance of your system. Also, feel free to contact me with any specific questions you may have.

After you have completed collimation, you can remove the crosshair. You should note the difference in the appearance of a bright star with and without the crosshair. You will notice immediately another advantage of having an unobstructed aperture: Yolos have no diffraction spikes!

I would like to thank my wife Stasi for her enduring patience where my obsession for optics is concerned.

James Mulherin
Torus Optical
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Iowa City, IA 52240

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Ross Null Software

The Ross Null test, described in detail by David Stoltzmann and Peter Ceravolo in TM#39, provides a convenient way to test a telescope mirror. By making a parabolic mirror appear spherical to the tester, the Ross Null test eliminates the tedious and somewhat imprecise measurements of the Foucault test and zonal mask. Errors in the mirror surface are immediately obvious because any shadows indicate departures from the ideal figure.

In the original article, a series of graphs are used to determine the correct spacing between the tester, lens, and mirror. (Setting up the test is quite simple once you know the required spacings.) Although the graphs in the article make the test accessible to TMs who don;t own a computer, it is not the best method since a lens and mirror combination can easily fall beyond the range of the graphs and the lens is limited to a plano-convex shape (any positive shape lens, i.e. double-convex, can be used with the Ross null test). Also the user does not know how much residual aberration the combination has.

Following Peter Ceravolo's suggestions, I have written a program for PC and Macintosh computers that allows test users to make a rapid, effortless calculation of the required spacings.

Program Operation

On starting the program, you will be prompted for the mirror diameter, focal length, and conic constant (0 for a parabola) which is equal to 1-(eccentricity)2.

Next, you will be asked for the lens-to-surface radius on the image side, the radius on the mirror side, the center thickness of the lens, the diameter of the lens, and the refractive index of the lens at the wavelength you are using. All parameters involving length must be expressed in inches.

If you are using a plano-convex lens (the most commmon configuration), then the radius on the image side is infinite (i.e., the surface is flat), so you should enter a large number such as 9e99. The mirror-side radius will be negative for a plano-convex lens.

If you are you using a bi-convex lens, the first radius will be positive and the second will be negative. The mirror radius is always positive in this program. The diameter of the lens is used only in determining the distance the lens is moved in each iteration, so if the program fails to converge try making this number larger.

Finally, you will be asked for the distance from the lens to the mirror. If you want the program to determine this value, enter a zero, otherwise you can enter a separation and the program will determine the resulting spherical aberration. This feature is useful in checking the sensitivity of your setup to positioning errors.Once this information is entered, the program will print intermediate results as it converges on the solution.

This program does not perform any error checking other than error checking in the compiler that could alert the user to an impossible configuration. Furthermore, the prograam does not check the validity of inputs. Macintosh users, for example, should not use the enter key on the numeric key pad to input data because doing so may cause the program to crash.

The intermediate results help you keep an eye on the program operation. When the computer has iterated the spherical aberration down to a reasonable value, it will print a summary.

The summary includes the object to lens distance, lens to mirror distance (measured between their centers), the working diameter of the lens (at the surface closest to the mirror), the residual spherical aberration at the 70% zone, the marginal spherical aberration (for the edge and center rays), the quarter-wave tolerance for knife edge shift (you must divide this by two if your source and knife edge move together), and the maximum optical path difference (expressed in waves) for the 70% zone when the marginal spherical is zero.

The optical path difference (OPD) should be significantly smaller than the desired mirror quality because the test set up will then be less sensitive to spacing errors and misalignments. To reduce the residual OPD to an insignificant amount (less than 1/20 wave on the wavefront) you should use large-diameter, long focal length lens. The program makes it easy to experiment with different lenses to achieve

the optimum correction.

Finally the working diameter of the lens is important, this is the absolute minimum clear aperture that you will need to see the whole mirror from the tester. Because no lens is perfect and because most imperfections occur at or close to the edge, the lens should be at least one inch larger than the program indicates.

This program works for non-parabolic mirrors such as the hyperbolic primary of a Ritchey-Chretien or an elliptical primary for a Dall-Kirkham telescope. I cannot guarantee that the results will converge for an arbitrary combination of lens and mirror. After all, there may not be a solution.

ROSS NULL TEST SETUP CALCULATIONS
(EXAMPLE)

Mirror Parameters

Diameter		12.5
Focal Length		50
Conic Const.	=	1 - Eccent. ** 2
Parabola	=	0, Sphere = 1
Conic Constant		0

Lens Parameters

Sign Convention:
With mirror on right,) = -ve, (= +ve

Image Side Radius	9e99
Mirror Side Radius	10.07
Thickness	0.442
Diameter	3.5
Refractive Index	1.514323
Enter Lens To Mirror Distance Or Enter 0 to Calculate	0

Results:

Object to Lens Distance	=	9.807996
Lens to Mirror Distance	=	79.195408
Working Diameter of Lens	=	2.619529
70% Zone Spherical Aberration	=	-0.000534
Marginal Spherical Aberration	=	-0.000092
Quarter-wave Tolerance	=	0.004617
Maximum Optical Path Difference	=	0.028908

Copyright (c) 1990, Doug George
All Dimensions in Inches

Program Description

I wrote this program in Turbo Pascal. The accompanying program listings are simplified to use standard Pascal so the program should work with almost any Pascal compiler. The source code for both the PC and Macintosh is available on disk, and an executable program is provided on both PC and Mac disks. The PC version includes a few extra features such as an optional graphics display.

The program takes about 10 seconds to run on a 25MHz 80386 computer, and executes even faster with a math co-processor. The program calculates the lens spacing by performing a ray trace of the optical system. It guesses at a starting position of the lens relative to the mirror, and adjusts that position until the spherical aberration is minimized.

The program consists of several subroutines for clarity. These are as follows:

The ArcSin and Power routines perform some simple math functions which the compiler does not provide. The AsphericReflectRay, TraceRay, and Transfer routines perform the ray-trace mathematics. AsphericReflectRay determines the point at which the light ray intersects the mirror. An eight-order approximation to the aspheric is used, and the intersection point is determined iteratively using a gradient method. Once the intersection point is determined, simple geometry determines the reflection path.

TraceRay calculates the deflection of a light ray as it passes through a lens surface. Transfer carries the light ray from one surface to the next. CalculateLi uses the ray tracing routines to trace the path of a single light ray through the optics. Given the positions of the lens and mirror, it determines the resulting distance between them.

If spherical aberration is present, the height of the ray affects the focus point. Therefore, the height of the ray striking the first surface of the lens must also be entered. The routine calculates the ray height at the other optical surfaces along the way. CalculateLo determines the correct place to put the object (light source) so that the image falls in the same place.

This is done iteratively by moving the object slightly toward the image and determining the new image point using CalculateLi. This process is repeated until the difference is sufficiently small.

CalculateSA takes as input the guess at the correct distances between the mirror, lens, and object (light source). It also needs the mirror semi-diameter, and a guess at the height of a marginal ray at the first surface of the lens. It uses CalculateLo to determine the object spacing, and then adjusts the ray height to keep the light ray intersecting the mirror edge.

CalculateLo is then called again to tweak up the object distance. CalculateLi is then used to determine the image distance for a ray at 10% of the marginal height. The difference in the image positions for these

two rays gives the spherical aberration from center to edge. The CalculateSA routine is used iteratively by the main program to determine the correct lens spacing.

After prompting the user for the required input, initial guesses are made for the spacings and marginal ray height at the lens. Another parameter, AdjustGain, is calculated based on the focal ratio. For a given spherical aberration, this increases the position adjustment for a long focus mirror, and reduces it for a fast mirror. This ensures rapid convergence on the solution without the mathematics going unstable.

The main loop calculates the spherical aberration given the present guessed parameters. It multiplies the resulting spherical aberration by the AdjustGain factor to determine the amount to adjust the mirror to lens spacing. Each time the spacing is moved, it comes closer to the optimum value. The loop exits when the residual aberration is negligible.

With the marginal spherical aberration nearly at zero, the residual error in the test will be the error at the 70% zone. The program calculates this and outputs the result summary.

Program Testing

If you type the listing that accompanies this article, be sure to test the program to ensure it is working properly. The example below shows the program input and output for a sample optical setup. Enter the same data and verify that the results are similar.

Note that small differences in mathematical precision from different compilers and computer types may result in slightly different numerical results.

Obtaining a Copy of the Program

Obtaining the source code and a compiled version of this program is as easy as mailing a formatted diskette in a self-addressed stamped mailer to Telescope Making in Milwaukee. The program files will be copied onto your diskette and mailed back to you. This program is free, so you are free to give copies to your friends.

Summary

This program greatly simplifies the use of the Ross Null test. The optical setup can be determined in a matter of seconds, and the probability of error is reduced.

The sensitivity of the test to the placement of the mirror and lens can be determined by manually entering values to either side of the optimum positioning. Be careful and double check your results. Remeber that the old adage, "garbage in, garbage out" applies here.

The first time tou use this test, test a mirror of known quality. Mistakes in the test setup or problems with the null-test lens will be immediately obvious.

When you are figuring a mirror, cross-check the results with a Foucault test or another method — after all, you don't want to pull a Hubble! I would like to thank Peter Ceravolo for his valuable assistance and encouragement in the preparation of this article and program.

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Kanata, Ontario
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Editor's Notes: Lenses For the Ross Null Test

Obtaining a suitable lens is the biggest hurdle you'll face in using the Ross null test. Even if you purchase a lens from a reputable supplier of stock lenses, you cannot be sure of the quality.

One option to consider is to make a lens from scratch, but doing so is a chore. Refurbishing an existing lens is considerably less work because the surfaces are only likely to need touching up with a polishing tool.

If you get lucky you may run into high quality lenses in a surplus store. Bob Sandness (263 Burns Blvd., King City, Ontario, L0G 1K0, Canada) had such luck. In fact he struck gold! Bob has obtained a stack of lenses. Some are 6.3 inches in diameter with a 17.6-inches focal length, while others are 5 inches in diameter and have an 11.3-inch focal length. Bob is offering these lenses to TM readers for $15 apiece. This covers the cost of the lens and shipping within the continental USA and Canada.

I have tested most of these lenses and found them to have very good surface quality. Careful measurement of the back focal length and radii indicate that the 6-inch lenses are BK7 with a red-light index of 1.514. The 5-inch lenses are SF2 with a red light index of 1.644.

The lens diameters are rather large for their focal lengths. For a 12.5-inch f/4 or a 20-inch f/5 mirror the working diameter of the 6-inch lens is only 2.5 inches and the residual wavefront aberration amounts to $^1/_{30}$ wave for both mirrors.

When the 5-inch lens is combined with these mirrors, the working diameter of the lens is 1.4 inches and yields a $^1/_{16}$-wave wavefront for the 12.5-inch and $^1/_{20}$ wave wavefront for the 20-incher.

These lenses are just about ideal for most mirrors. However, to achieve an even better null, you could lengthen the radius of one lens surface. The resulting lens would have even lower residual abberation.

Experiences from the "Oops!" file

While I have been living and breathing optics for some fifteen years and making them professionally for over ten years, I am still amazed at some of the bonehead mistakes I make at the polisher or at the testing stand. We seem to learn much more from our mistakes than our successes, so I think it is important that we TMs talk about our failures as well as our triumphs. To that end I offer these two little tidbits that apply to the Ross null test.

Astigmatism is difficult to detect with the standard Foucault test but can be easily seen with a very small pinhole and a high powered eyepiece at the center of curvature of a telescope mirror before it is parabolized. Such testing can be difficult to perform because small pinholes are hard to make and difficult to position without special equipment. But astigmatism and the need to test for it can be avoided entirely with the proper grinding and polishing techniques.

While I was grinding and polishing a 10-inch f/5.7 full-thickness mirror (by machine and face up) I didn't bother to take the usual precautions to support the mirror properly. Instead of resting the the mirror on carpet, I stuck it to the grinding machine turntable with three pads of spongy, double-sided mounting tape about 1 inch square placed 120 degrees apart at the 70 percent zone. I merrily worked the surface. After achieving a good polish I spent a weekend figuring the mirror with the Ross null test. I tweaked the figure until I saw no trace of shadows; it was a clean null.

After aluminizing the primary I installed it in the telescope and found the star images to be astigmatic!

The Zygo interferometer at work revealed the mirror had 0.4 waves of astigmatism. The sad part was that when the astigmatism was subtracted from the test data (the fringe analysis software allows one to subtract a variety of aberrations) the peak-to-valley wavefront error was about $^1/_{15}$ of a wave!

Such is the price of carelessness. I have never had a problem with astigmatism at the eyepiece before, even with a 12.5-inch mirror only 1.25 inches thick, since I exercised good process control and didn't feel the need to even test for it. I finally got caught!

The article in TM#39 failed to mention that the Ross null lens acts as a focal reducer. TMs know that the sensitivity of the Foucault test decreases with the the radius of the mirror being tested. A $^1/_4$-wave zone is much easier to see in an f/8 mirror than it is on an f/4 mirror. I figured a 12.5-inch f/6 mirror with the setup pictured in TM#39. The figure was not perfect, but I was in a hurry to call it finished. Although I could see zones I thought the edge looked good and the mirror would be a fine performer. However, some telescope makers tested it with the Foucault test and a zonal mask and found it to be accurate to only $^1/_3$-wave and most of that was in the form of edge roll, and they told me about it.

Well, I admit I was sceptical. I am not really fond of zonal mask readings. I took the mirror back and tested it by autocollimation and discovered that it did indeed suffer from a $^1/_4$-wave edge roll. Time for me to eat crow!

I now know how some of the commercial telescope makers that I've haunted feel! This experience illustrates the problems one encounters with the subjective nature of the Foucault or Ronchi null tests.

When I figure with the Ross null I generally keep working the surface until I see no significant zones. Although it takes forever, I do this so I don't have to worry about quantifying a hard-to-measure zone to verify that it is within spec. One can really go overboard this way, spending an excessive amount of time and effort elliminating zones that would probably have no visible effect on the mirror's images, all the while worrying that the already-good figure might go awry and set you back hours.

The bottom line is that while the Ross null was very accurate (meaning it produced a $^1/_{150}$-wave null on the wavefront for this mirror), it was not sensitive enough when used with a Foucault tester.

A $^1/_4$-wave defect at the 147.3-inch center of curvature of the mirror in question causes a knife-edge shift of 0.050 inches, which is pretty easy to measure. However, with the Ross lens is placed in the converging beam, the focal reducing effect increases the speed of the beam to f/5.

Under these conditions a $^1/_4$-wave error on the wavefront causes only a 0.009-inch knife-edge shift (and only 0.0045 inches shift if the source and knife-edge move together) and that is easy to see but very difficult to measure.

The problem worsens with faster mirrors. A 12.5-inch mirror of 50 inches focus with my Ross null lens would produce an f/3.8 beam at the tester, and the $^1/_4$-wave knife-edge shift would be a mere 0.004 inches. The only way out of this dilemma is to use interferometry, (see Scott Miligens letter in TM#43), and that's still beyond the reach of most TMs.

The moral of the story is to keep on polishing until the mirror looks perfect!

—Peter Ceravolo

```
{-------------------------------------------------------------}
{                                                             }
{                                                             }
{ Name:  RossNull                                             }
{                                                             }
{                                                             }
{ Location: ROSSNULL.PAS                                      }
{                                                             }
{                                                             }
{ Purpose:  Calculates setup for Ross Null test               }
{       Refernce: Modern Optical Enginneering                 }
{       by Warren J. Smith                                    }
{                                                             }
{                                                             }
{ Copyright (c) 1989 by Doug George                           }
{ This program may be distributed freely provided the copyright }
{ notices are not removed.                                    }
{                                                             }
{                                                             }
{-------------------------------------------------------------}
program RossNull;


{-------------------------------------------------------------}
{                                                             }
{                                                             }
{ Global Constants and Variables                              }
{                                                             }
{                                                             }
{-------------------------------------------------------------}


const
        LDelta = 1e-4;
        SAResidual = 1e-4;
        mSemiDTol = 0.1;
        Pi = 3.141596535;
        HalfPi = 1.570796327;
        XOffset = 31;
        RadToDeg = 57.29577951;


var
        mSemiDiameter, mRadius, mConicConst: extended;
        IRadiusI, IRadiusM, IThick, IIndex: extended;


{-------------------------------------------------------------}
{                                                             }
{                                                             }
{ Name:  ArcSin                                               }
{ Purpose:  Calculate arcsin function                         }
{                                                             }
{                                                             }
{-------------------------------------------------------------}


function ArcSin (X: extended): extended;
        begin
            if abs(X) < 1.0 then
                ArcSin := ArcTan(X / Sqrt(1.0 - Sqr(X)))
            else if X < 0.0 then
                ArcSin := -HalfPi
            else
                ArcSin := HalfPi;
        end;


{-------------------------------------------------------------}
{                                                             }
{                                                             }
{ Name:  Power                                                }
{ Purpose:  Raise a variable to a power                       }
{                                                             }
{                                                             }
{-------------------------------------------------------------}


function Power (X, Y: extended): extended;
        begin
            if X < 0 then
                Power := -exp(Y * ln(-X))
            else if X = 0 then
                Power := 1
            else
                Power := exp(Y * ln(X));
        end;


{-------------------------------------------------------------}
{                                                             }
{                                                             }
{ Name:  AsphericReflectRay                                   }
{ Purpose:  Traces the ray through a reflection off a mirror  }
{    with ellipsoid, paraboloid, or hyperboloid surface       }
{                                                             }
{                                                             }
{-------------------------------------------------------------}
```

```
procedure AsphericReflectRay (var Q: extended;  { Perpendicular distance of ray to vertex of element }

                    var U: extended;  { Angle of input }
                    var Y: extended;  { Height of intersection }
                    p: extended;  { Conic Constant }
                    r: extended); { Radius of surface }

        var
            x, xEst: extended;
            A2, A4, A6, A8: extended;
            G, m: extended;
            Phi: extended;
            Xdir, Ydir: extended;

        begin
            r := -r;

{ Calculate constants for this aspheric }
            A2 := 1 / (2 * r);
            A4 := p / (8 * Power(r, 3));        { 0 for parabola }
            A6 := sqr(p) / (16 * Power(r, 5));    { 0 for parabola }
            A8 := Power(p, 3) / (25.6 * Power(r, 7)); { 0 for parabola }

{ Calculate position of incidence if the mirror was flat }

            y := Q;
            x := 0;

{ Calculate direction cosines }
            Ydir := sin(U);
            Xdir := cos(U);

            repeat
 { Calculate value of x given this y for an aspheric surface }
                xEst := A2 * sqr(y) + A4 * Power(y, 4) + A6 * Power(y, 6) + A8 * Power(y, 8);

 { Calculate gradient to correct answer }
                m := -y * (2 * A2 + 4 * A4 * sqr(y) + 6 * A6 * Power(y, 4) + 8 * A8 * Power(y, 6));
                G := (xEst - x) / (Xdir + Ydir * m);

 { Estimate new value }
                x := G * Xdir + x;
                y := G * Ydir + y;
            until abs(x - xEst) < 0.0001;

{ We now have x and y coordinates of intercept point with aspheroid }
{ Calculate angle between normal and x-axis, then calculate new U }
            Phi := ArcTan(-y / (r - p * x));
            U := 2 * Phi - U;

            Q := cos(U) * y;

        end;
```

```
{-------------------------------------------------------------------------}
{                                                                         }
{                                                                         }
{ Name:  TraceRay                                                         }
{ Purpose:  Traces the ray through a surface                              }
{ Status:  Fully debugged for curved and flat surfaces                    }
{                                                                         }
{                                                                         }
{-------------------------------------------------------------------------}
```

```
procedure TraceRay (var Q: extended;  { Perpendicular distance of ray to vertex of element }
                    var U: extended;  { Angle of input }
                    var Y: extended;  { Height of intersection }
                    N: extended;  { Refractive index of input media }
                    Np: extended; { Refractive index of output media }

                    r: extended); { Radius of surface }
        var
            I, SinI, Ip, Up, G: extended;
        begin

{ Meridional Ray Trace Equations }

{ Calculate angle of incidence }
            SinI := Q / r - sin(U);
            I := ArcSin(SinI);

            Y := Q * (1 + cos(U + I)) / (cos(U) + cos(I));


{ Law of refraction to calculate outgoing ray angle of incidence }
            Ip := ArcSin(N / Np * SinI);


{ Calculate output angle from geometric additions }
            Up := U + I - Ip;


{ Calculate output rayheight using formula which is stable for flat surface }
            G := Q / (cos(U) + cos(I));
            Q := G * (cos(Up) + cos(Ip)); { Actually Qp }

{ Copy new Up into U }
            U := Up;

        end;
```

```
{-------------------------------------------------------------------------}
{                                                                         }
{                                                                         }
{ Name:  Transfer                                                         }
{ Purpose:  Transfers the ray to the next surface                         }
{                                                                         }
{                                                                         }
{-------------------------------------------------------------------------}
```

```
procedure Transfer (var Q: extended;  { Perpendicular distance of output ray to element vertex }
                    Up: extended;  { Angle of output }
                    t: extended); { Distance to next surface }

        begin

{ Transfer to Next Surface }
            Q := Q - t * sin(Up);
        end;
```

```
{-------------------------------------------------------------------------}
{                                                                         }
{                                                                         }
{ Name:  CalculateLi                                                      }
{ Purpose:  Calculates the distance to the image from the                 }
{           lens' last surface                                            }
{                                                                         }
{                                                                         }
{-------------------------------------------------------------------------}
```

```
procedure CalculateLi (Y: extended;      { Height of ray at lens' first surface }
                       L: extended;      { Distance of object from lens }
                       S: extended;      { Distance to mirror }
                       var Li: extended;     { Distance to image }
                       var Y1: extended;     { Ray height at lens' second surface }
                       var Y2: extended);    { Ray height at mirror }

        var
            Q, U: extended;

        begin

{ Opening: Calculate initial U and Q }
            U := arctan(Y / (-L));
            Q := -L * sin(U);

{ Trace through each element }
            TraceRay(Q, U, Y, 1.0, IIndex, IRadiusI);

            Transfer(Q, U, IThick);
            TraceRay(Q, U, Y1, IIndex, 1.0, IRadiusM);

            Transfer(Q, U, S);
            AsphericReflectRay(Q, U, Y2, mConicConst, mRadius);

            Transfer(Q, U, -S);
            TraceRay(Q, U, Y, 1.0, IIndex, IRadiusM);

            Transfer(Q, U, -IThick);
            TraceRay(Q, U, Y, IIndex, 1.0, IRadiusI);

{ Closing: calculate distance }
            Li := Q / sin(U);

        end;
```

```
{-------------------------------------------------------------------------}
{                                                                         }
{                                                                         }
{ Name:  CalculateLo                                                      }
{ Purpose:  Calculates the required distance from the                     }
{     object to the lens' first surface                                   }
{                                                                         }
{                                                                         }
{-------------------------------------------------------------------------}
```

```
procedure CalculateLo (Y: extended;     { Height of ray at lens }
                       S: extended;     { Distance from Lens to Mirror }
                       var Lo: extended);   { Calculated Lo }
        var
            Li, Y1, Y2: extended;
        begin
            CalculateLi(Y, Lo, S, Li, Y1, Y2);
        repeat
 { If not close enough, re-iterate }
            if abs(Lo + Li) >= LDelta then
        begin
```

```
            Lo := Lo - (Lo + Li) * 0.3333333333;
        end;

            CalculateLi(Y, Lo, S, Li, Y1, Y2);

            until abs(Lo + Li) < LDelta;
        end;


{-------------------------------------------------------------------}
{                                                                   }
{                                                                   }
{ Name:  CalculateSA                                                }
{ Purpose:  Given mirror-lens spacing, mirror semi-diameter,        }
{     initial ray height at lens' first surface, and                }
{     an initial object distance spacing, calculates                }
{     required object spacing (based on edge ray), new              }
{     ray height, and determines the resulting                      }
{     spherical aberration between edge ray and                     }
{     centre ray                                                    }
{                                                                   }
{                                                                   }
{-------------------------------------------------------------------}

procedure CalculateSA (S: extended;  { Mirror-lens spacing }
                       H: extended;  { Mirror semi-diameter }
                       var Lo: extended;  { Initial object distance to update }
                       var Y: extended;  { Initial lens ray height to update }
                       var SA: extended); { Minimum Spherical Aberration given S }
        var
            Li10, Li100, Y1, Y2: extended;
        begin

{ Determine object distance (= image distance) for 100% ray }
            CalculateLo(Y, S, Lo);


{ Adjust Y to keep Y2 close to mirror edge }
            CalculateLi(Y, Lo, S, Li100, Y1, Y2);
            Y := Y * H / Y2;


{ Recalculate Lo with new diameter }
            CalculateLo(Y, S, Lo);


{ SA: Calculate Li at 10% }
            CalculateLi(Y * 0.1, Lo, S, Li10, Y1, Y2);

            SA := Li100 - Li10;
        end;


{-------------------------------------------------------------------}
{                                                                   }
{                                                                   }
{ Name:  Mainlin                                                    }
{ Purpose:  Performs Ross Null setup calculations                   }
{                                                                   }
{                                                                   }
{-------------------------------------------------------------------}


        var
            Lo, Li10, Li70, Li100, S, Y, Y1, Y2, SA, Tol, OPD: extended;
            Ch: char;
            I: integer;
            AdjustGain, Adjust, IFl, IDiameter: extended;
            JustCheck: boolean;


begin

        writeln('Ross Null Test Setup Calculations V1.1');
        writeln('Copyright (c) 1990, Doug George');
        writeln('66 Shetland Way, Kanata, Ontario, Canada, K2M 1S4');
        writeln('This shareware program may be freely distributed and used.');
        writeln;
        writeln('All Dimensions in Inches');
        repeat
            writeln;
            writeln('Mirror Parameters');
            writeln;
            write('Diameter          -> ');
            readln(mSemiDiameter);
            mSemiDiameter := mSemiDiameter * 0.5;


            write('Focal Length        -> ');
            readln(mRadius);
            mRadius := -abs(2 * mRadius);


            writeln('Conic Const. = 1 - Eccent. ** 2');
            writeln('Parabola = 0, Sphere = 1');
            write('Conic Constant       -> ');
            readln(mConicConst);

            writeln;
            writeln('Lens Parameters');
            writeln;
            writeln('Sign Convention:');
            writeln('With mirror on right, ) = -ve, ( = +ve');
            writeln;
            write('Image Side Radius     -> ');
            readln(IRadiusI);


            write('Mirror Side Radius     -> ');
            readln(IRadiusM);

            write('Thickness          -> ');
            readln(IThick);

            write('Diameter           -> ');
            readln(IDiameter);

            write('Refractive Index      -> ');
            readln(IIndex);
            writeln;


{ Calculate lens focal length }
            IFL := 1.0 / ((IIndex - 1) * (-1.0 / IRadiusM + 1.0 / IRadiusI));

            writeln('Enter Lens To Mirror Distance');
            write('Or Enter 0 to Calculate   -> ');
            readln(S);
            JustCheck := S 0;
            writeln;


{ Guess initial Lo based on 1/2 lens focal length }
            Lo := IFL * 0.5;


{ Guess S at mirror radius minus lens focal length }
            if not JustCheck then
                S := -mRadius - IFL;


{ Guess Y from simple geometry }
            Y := (mRadius + S) / mRadius * mSemiDiameter;


{ Pick a useable adjustment gain factor using mirror and lens F/ratio }
            AdjustGain := Power(-mRadius / mSemiDiameter / 4, 1.5) * IFL / IDiameter;

            repeat

                CalculateSA(S, mSemiDiameter, Lo, Y, SA);

                writeln('Object-Lens = ', Lo : 11 : 6, ' Lens-Mirror = ', S :
                11 : 6, ' Marginal SA = ', SA : 11 : 6);

                if (abs(SA) > SAResidual) and not JustCheck then
                    begin
                    Adjust := SA * Adju Gain;
                    if Adjust > 1 then
                        Adjust := 1
                    else if Adjust < -1 then
                        Adjust := -1;
                    S := S + Adjust;
                end;

                until (abs(SA) < SAResidual) or JustCheck;

{ Calculate a few output parameters }
            CalculateLi(Y * 0.1, Lo, S, Li10, Y1, Y2); { To get Li10 }
            CalculateLi(Y * 0.7, Lo, S, Li70, Y1, Y2); { To get Li70 }
            CalculateLi(Y, Lo, S, Li100, Y1, Y2);   { To get Y1 }
            Tol := 0.008 / 25.4 * sqr(Lo / (2 * Y));

            OPD := abs(Li70 - Li10);
            if OPD < abs(Li100 - Li10) then
                OPD := abs(Li100 - Li10);
            if OPD < abs(Li100 - Li70) then
                OPD := abs(Li100 - Li70);
            OPD := OPD / (4 * Tol);

            writeln;
            writeln;
            writeln('Results:');
            writeln;
            writeln('Object to Lens Distance    = ', Lo : 11 : 6);
            writeln('Lens to Mirror Distance    = ', S : 11 : 6);
            writeln('Working Diameter of Lens   = ', Y1 * 2 : 11 : 6);
            writeln('70% Zone Spherical Aberration  = ', Li70 - Li10 : 11 : 6);
            writeln('Marginal Spherical Aberration  = ', Li100 - Li10 : 11 : 6);
            writeln('Quarter-wave Tolerence    = ', Tol : 11 : 6);
            writeln('Maximum Optical Path Difference = ', OPD : 11 : 6);
            writeln;
            write('Another Setup? (Y/N) ');
            readln(Ch);
        until (Ch 'y') and (Ch 'Y');
end.
```

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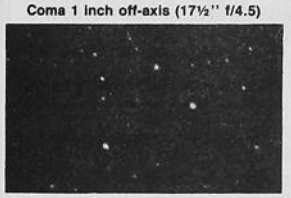

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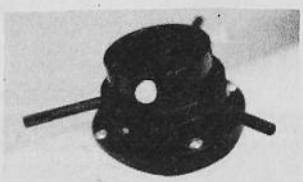

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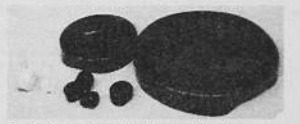

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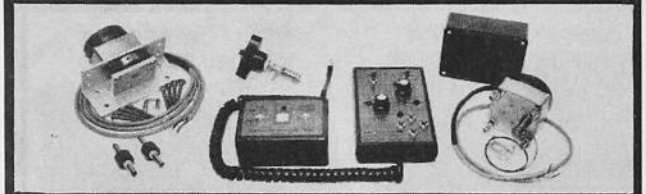

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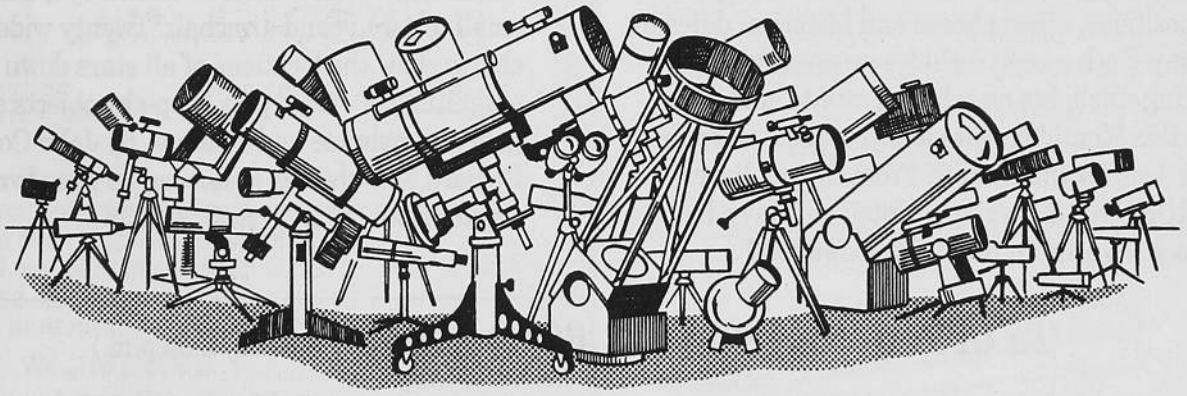

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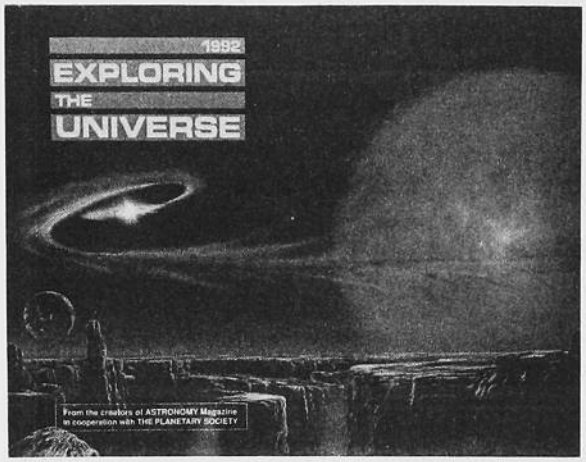

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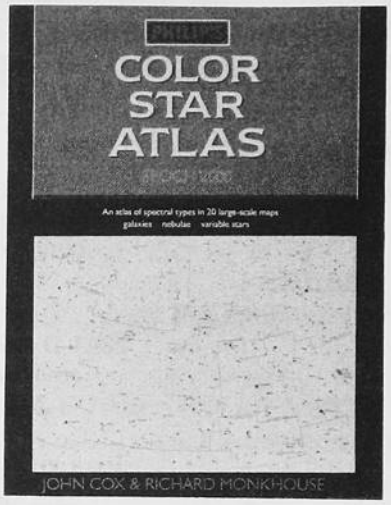

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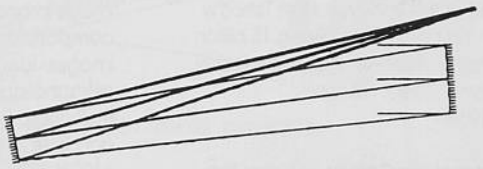

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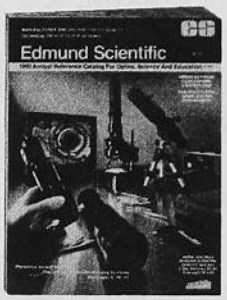

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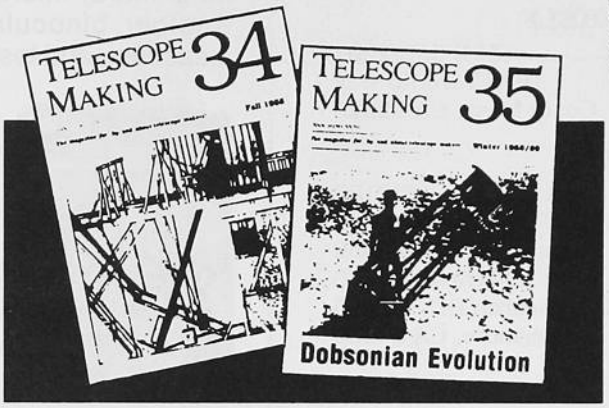

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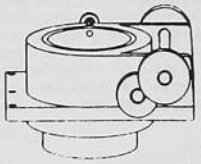

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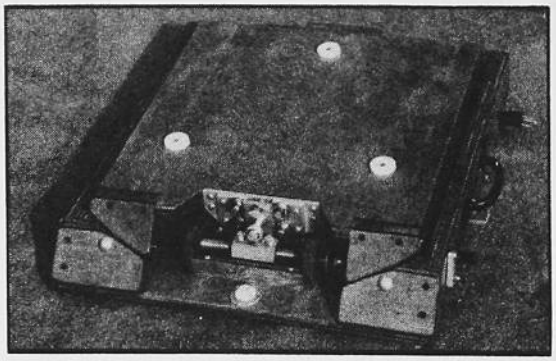

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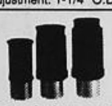

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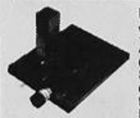

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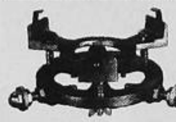

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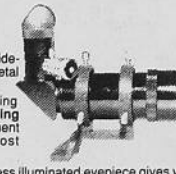

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It's a fantastic viewfinder. It's a versatile rich-field telescope. It's a compact nature study scope. It has an Amici prism for correctly oriented images. We added a fine quality rack and pinion, a crosshair eyepiece, and a camera tripod mounting block to round out the package. Beautiful satin black finish—**$279.95**

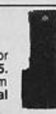
Our binocular viewer lets you use both eyes for increased visual acuity!

Our years of experience supplying binocular viewers assure you the finest product on the market. Our unit features the exclusive removable multi-coated Barlow image transfer lens system. Our unit fits any 1-1/4" telescope. Interpupillary adjustment with indexed scale–**$449.00**

Parabolic Mirrors—our Master Optician Series™ will meet your most exacting requirements.

Let's forgo the usual ad writer's hyperbole concerning mirror quality and simply say that if these are not the finest quality telescope mirrors you have ever seen, return them and *we will refund your money, no questions asked!* The best part is we can usually give off-the-shelf delivery when you are in a hurry to start your telescope. **Available in 6" f/5, 6" f/8, 8" f/6, and 10" f/6. Please call for prices.**

Accessories for Schmidt-Cassegrain Telescopes.



Camera quality visual and photographic accessories for your Meade or Celestron telescopes. **T-adapter–$27.95. Telextender–$27.95. Telecompressor** (larger 36mm size with extension tube)–**$56.95, Deep-sky f/5 Visual Adapter–$89.95, Off-axis Guider Body only $65.95**

The latest Willmann-Bell publications.

All book prices are postage-paid.

Uranometria 2000.0 Volume 1 .... $39.95
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Astro Formulae for Calculators. Meeus $14.95
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How to Make a Telescope, 2nd Edition. Texereau $19.95
Astrophotography. Gordon $18.95
Astrophotography II. Martinez $18.95
Advanced Telescope Making Techniques, Volume I $19.95
Advanced Telescope Making Techniques, Volume 2 .... $19.95
Telescope Optics, Evaluation and Design. Rutten and VanVenrooij $24.95
Introduction to Observing and Photographing the Solar System. Dobbins, Parker, and Capa $19.95

Pretoria™—Is this perhaps the world's first professional telescope ocular?

The October 1988 product review in *Astronomy* states: "If you are looking for the perfect eyepiece for your fast Newtonian reflector, the Pretoria eyepiece is it." While the Pretoria does eliminate coma in fast Newtonians, it can dramatically improve the performance of any Newtonian. 25mm of eye relief in the 28mm model for those who must wear glasses. Multi-coated optics. For 2" or 1-1/4" holders.

28mm $225.00

Exciting new additions to the Wide Scan™ lineup!

We have some new additions to the world's most exciting line of compact, lightweight, and affordable 80° plus eyepieces. The new **16mm** with an 84° field gives a brilliant performance. All **Wide Scans™** feature only the finest select Japanese optics throughout. Full multi-coating. The 82° field **6mm** and **8mm** will be available in the summer of 1990.

16mm... $140.00, 8mm... $125.00, 6mm... $125.00

A wide variety of adapters to help you get the most from your telescope

Professional Camera Adapter couples your camera to any 1-1/4"" focuser. For first focus and eyepiece projection. Use with camera T-ring listed below—**$34.95**

For Imported Scopes. Same high quality as above but fits 0.96 telescope–**$29.95**

2" Prime Focus Adapter. For prime focus in 2" systems. You do need aT-ring for your camera–**$24.00**

ORDER FORM

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Charge My: ☐ VISA ☐ MasterCard

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Paracorr™ Eats Coma

At Last, a *Universal* Coma Corrector for Parabolic Mirrors

There's no question large aperture reflectors like John Vogt's excellent 30" f/3.8 produce deep sky views rivaling those I've seen in major observatories. But his scope, like yours, is limited in field sharpness. The main offender is coma, an aberration which makes stars look like blurry comets. Visually and photographically, the faster the scope the worse the effect.

If we compensate for coma before starlight reaches the eyepiece, then the best eyepieces will be used to fullest advantage, and a sharp full frame 35mm photograph is possible. In sum, my design goals were:

1. maximum reduction in coma and field curvature without compromising spherical aberration and color correction

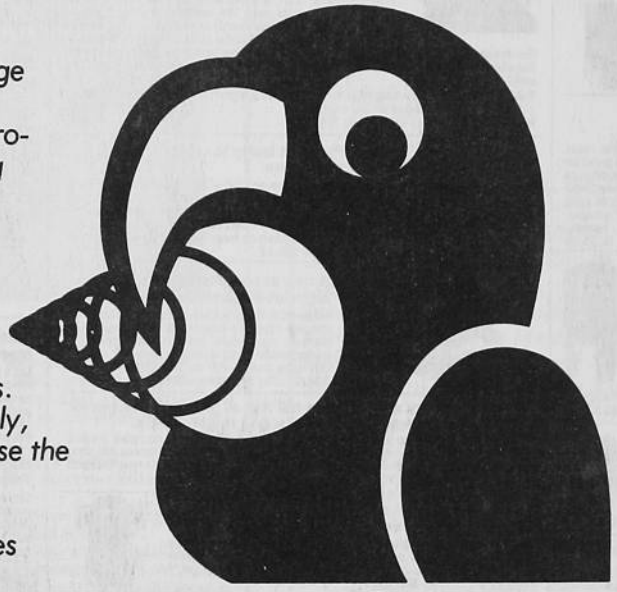
2. major sharpness improvement for all popular focal ratios

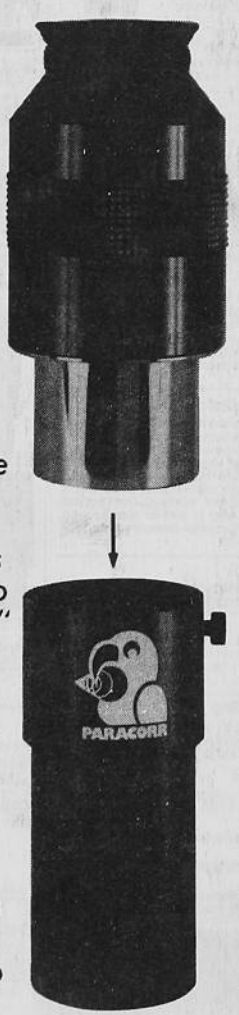
3. equally effective visually or for 35mm film

4. as convenient to use as a Barlow lens

I hope you agree that Paracorr, the coma eater, is the missing link necessary to fully enjoy your "DobNewt."

—Al Nagler





The Formula For Increasing Sharp Field

A perfectly made 13" f/4.5 parabola has only about .1° diffraction-limited field. Now add Paracorr plus a Nagler eyepiece to your f/3.5–f/8 parabola and tremendously increase your sharp field. Extract all the performance the atmosphere and your mirror quality will allow. Since Paracorr tightens and intensifies star images, enjoy resolving globular clusters as they drift right to the edge of your field of view. No more finding the "sweet spot" of focus. The entire field is your "sweet spot"!

Astrophotography

Rival a Schmidt Camera? Mount your 35mm SLR to Paracorr, and the quality of full frame photos will be spectacular since star image sizes are designed to be less than .001 inch over the field for an f/4.5 mirror.

Easy To Use

Paracorr drops in like a Barlow lens. With only a slight 1.15x magnifying factor, an f/4.5 telescope becomes an f/5.17. While optimized for Tele Vue eyepieces, other makes can be used. Of course the better the eyepiece, the better the results. The 1¼" Paracorr is parfocal with most Tele Vue eyepieces. The 2" Paracor requires about ½" in travel from your current focus location. Can't be simpler for any scope, any eyepiece, and any 35mm SLR camera.

Paracorr — The Missing Link

An optical chain is as good as its weakest link. With the development of 82° Nagler eyepieces, Tele Vue offers the largest, flattest and best corrected visual fields in the industry. Combine the Nagler revolution, Dobsonian revolution and Paracorr for the ideal mating for flat-field and sharpness, visually and photographically. Try Paracorr on your "DobNewt." We think you'll agree that the revolution is complete.

A) parfocal 2"-1¼" adapter
B) 2" eyepiece holder
C) lens assembly threaded for T-rings

2" Paracorr

1¼" Paracorr for visual use only.

Paracorr — More stars, sharper stars, more time to observe. Send $3 for full line literature package.

Tele Vue

20 Dexter Plaza, Pearl River, NY 10965
(914) 735-4044